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MACHINERY'S ENCYCLOPEDIA

VOLUME VII

INDEX AND GUIDE TO SYSTEMATIC READING

MACHINERY'S ENCYCLOPEDIA

A WORK OF REFERENCE COVERING PRACTICAL MATHEMATICS AND MECHANICS, MACHINE DESIGN, MACHINE CONSTRUCTION AND OPERATION, ELECTRICAL, GAS, HYDRAULIC, AND STEAM POWER MACHINERY, METALLURGY, AND KINDRED SUBJECTS IN THE ENGINEERING FIELD

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IN COLLABORATION WITH MANY PROMINENT MECHANICAL
AND ELECTRICAL ENGINEERS

VOLUME VII

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PREFACE TO INDEX

At first thought, it might be assumed that no index would be required in a work in which the sections or articles on the various subjects covered are alphabetically arranged. There are several reasons, however, why an index becomes necessary in an encyclopedia of so large a scope as the present work. While there are more than twelve hundred different subjects or main headings that may be referred to directly by making use of the alphabetical arrangement, there are, in addition, many thousands of subjects that have no separate main headings, but upon which information is given in connection with articles on other important phases of machine design and construction, shop practice, power plant equipment, electricity, metallurgy, etc. The information on these subjects is incorporated in the articles or sections comprised under some general heading, because it could not be given in an independent article without either sacrificing the best method of arrangement or necessitating useless repetition; further, many of the treatises are so comprehensive, and cover under one main heading so many subsidiary subjects, that it would require a considerable amount of time to find the information on any one phase of the main subject. The index, therefore, will make it possible to locate quickly the data contained on any specific topic, and to refer rapidly to every important subject in the ENCYCLOPEDIA. It also makes it possible to find, at a glance, all the information on any one subject, contained in the ENCYCLOPEDIA, even when the different phases may be treated in different parts of the work.

The ENCYCLOPEDIA has been very completely cross-indexed — that is, the same subject may be found by referring in the index to any of the main words that would be likely to be thought of in connection with it. The user of the ENCYCLOPEDIA should be cautioned, however, not to assume that a subject is omitted, simply because he does not find it under the first word that may enter his mind; should a subject not be found directly upon the first reference to the index, the user is advised to look up some other heading in the index, particularly one containing the most important word in connection with the topic in which he is interested.

The method of indexing requires but little explanation, as it is very clear and simple. The index of the ENCYCLOPEDIA is like the index of any other book, in that it refers to the volume and the page where the information sought will be found. In order, however, to still further facilitate reference to subject matter that may be inconspicuously given in the text, the index does not refer only to the page, but also to that part of the page where the reference will be found. This is done as follows: The reference, III, 265–*2*, indicates that the information sought is found on page 265 of Volume III; the last figure *2*, printed in "italics," shows that the reference is found in the lower left-hand column of that page. The figures *1*, *2*, *3*, and *4*, printed in italic type after the page number, each refer to one-fourth of the page; *1* indicates the upper half of the left-hand column; *2*, the lower half of the left-hand column; *3*, the upper half of the right-hand column; and *4*, the lower half of the right-hand column. The advantage of this simple method of arrangement of the index is apparent.

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GUIDE TO SYSTEMATIC READING

EVERY encyclopedia may be used for two purposes — as a reference work, consulted whenever information on any subject is required at a moment's notice, or for systematic study, in which case related articles would be read in accordance with an orderly plan, the reader thereby covering a complete course on any one topic. MACHINERY'S ENCYCLOPEDIA is no exception to this rule for the use of an encyclopedic work. It may be used either as a work of reference or as a means of obtaining a broad general knowledge of engineering and manufacturing practice. Its main purpose, and the reason for arranging the articles in alphabetical order, is, obviously, to make it convenient as a reference work and to replace a large library of mechanical books, in which it would be difficult to find rapidly the information required; used in this manner, these volumes will prove indispensable to designers, engineers, foremen, superintendents, and trained mechanics. It will be found, however, that this ENCYCLOPEDIA will serve the student in an equally satisfactory manner, provided he is aided in properly arranging his studies, so as to proceed from the simpler to the more difficult subjects essential to a comprehensive knowledge of mechanical engineering, in a logical orderly manner and according to a definite plan. This GUIDE TO SYSTEMATIC READING has, therefore, been prepared especially for the assistance of all those who will use the ENCYCLOPEDIA as a means of self-education rather than as a work of reference. It is intended to outline complete courses of study that may be covered by reading the articles in this work on the important subjects of mechanical engineering. These courses are outlined in such a manner that the successive order in which different subjects are taken up by the student will follow a definite plan.

Importance of Definite Plan in Study. — Everyone who knows — even in a general way — how machines of different classes are designed and constructed realizes that a definite order of procedure is essential. In the case of a new mechanical development, the designer or inventor must first know the requirements. The general type of mechanism or machine which will probably meet these requirements is first sketched roughly, and is then carefully designed; the parts required for the approved design are made and assembled, and, finally, the finished machine is tested. The entire procedure follows a definite plan. When studying the principles which are adhered to by the designer or constructor of machinery, it is equally important to proceed in an orderly and systematic manner. While it may be possible to acquire considerable knowledge by haphazard reading, it is quite obvious that the same information may be obtained with an expenditure of less effort and time, if the student takes up different subjects in their proper order. In fact, unless a systematic method of reading were adopted, it might be almost impossible to obtain a clear understanding of many important branches of engineering and machine manufacture.

The courses of reading or study outlined in this GUIDE, therefore, not only contain lists of articles pertaining to a general topic, but show the sequence or order in which the various articles or subdivisions of a main subject should be studied. This GUIDE also serves another important purpose in that it directs the attention of the student to many sources of information which might be overlooked in a general course of reading, either because they are in different parts of the ENCYCLOPEDIA, or because they would not be considered essential by those having had little or no experience along mechanical lines.

Importance of Definite Purpose in Study. — An attempt has also been made in this GUIDE to give the inexperienced man a clear understanding of the qualifications and requirements in different branches of mechanical work. A great many men who have not had the advantages of technical school training, or even of an apprenticeship, are ambitious to secure a better position by self-education, but are perplexed to know where to begin and what to study. The result is that much energy and time are wasted. Frequently, machinists take up mechanical drawing with the idea that the draftsman has a better job. Perhaps he has, but it is also true that a great many machinists who study to become draftsmen would ultimately have received greater benefit if the same amount of time had been devoted to the study of general manufacturing methods and shop practice, with a view to become shop foremen or superintendents. Many other examples of misguided effort, due, usually, to a misapprehension of the conditions, could be cited to prove that the best opportunity is often the one nearest at hand. The machinist or machine operator is often allured by the prospect of clean work in the drafting-room, but, in many cases, he has only a vague idea of what a competent draftsman needs to know.

Purpose of the Guide. — The editorial department of a publication like MACHINERY receives continually many requests for information and advice from men engaged in various branches of engineering and manufacturing work; these letters show that there is great need for general advice, even of a very elementary nature. It is for this reason that this GUIDE TO SYSTEMATIC READING includes, in addition to selected lists of articles, such general advice as has been considered helpful to many who will use this ENCYCLOPEDIA as a means of self-education. While this GUIDE has been prepared primarily for the student and men of limited education along mechanical lines, it will also prove useful to engineers and mechanical executives, because it arranges, in a logical order, the varied information on general subjects, and enables users of the work to gain a comprehensive idea of its scope and of the extent to which they may expect to find complete treatises on any one subject in which they are interested.

In using the ENCYCLOPEDIA for the purpose of study, it is strongly recommended that in every case the student first read the section in the GUIDE which relates to the subject which he intends to study, because this will give him a general perspective, and make it possible for him to obtain, in his mind, a proper correlation of the different subjects comprised in the course. The GUIDE also contains much mechanical information of a general nature, which will give the student a better grasp of the whole subject.

Selecting Courses of Study. — Many men who have obtained this ENCYCLOPEDIA especially with the view of increasing their knowledge of mechanical subjects generally will naturally ask themselves: Which is the best course of study? This is a question to which no direct answer can be given. Some men should be advised to study anything and everything that would be useful to them in an executive position, while, to many others, such advice, if followed, would mean simply disappointment and waste of time and effort. Some men do not possess the peculiar qualities that would enable them to ever rise to high executive positions, but it is safe to say that everyone ambitious enough to have acquired a set of these volumes possesses enough ability to become proficient in some one branch of mechanical work. Men of this type should concentrate all their efforts on the study of the kind of work in which they are engaged, or for which they feel the greatest inclination.

The subjects that a man should study must, therefore, largely be decided by himself. He should increase his knowledge of the work in which he is most interested — this will make both his work and study easier. If he is interested in drawing and has a natural ability for working out ideas or designs of his own, he should study drafting, machine design, mathematics, and theoretical mechanics, so as to utilize his natural inclinations to the best advantage. The young man whose sole interest is centered upon the practical operations in the shop would benefit more from studies of shop practice and manufacturing methods, because to him the shop, undoubtedly, offers the greatest possibilities. If he is familiar with shop practice and has acquired a knowledge of the use of the various machine tools, made a study of shop systems, and, in addition, has a personality which makes him capable of handling men, there is no reason why he should not rise to be a foreman or superintendent.

Systematic Study Brings Best Results. — While it is impossible to give an absolute rule which could be followed in acquiring a mechanical education, or to say which subjects are of the greatest importance to any individual, there is one rule that can be given to everyone without qualification or limitation, and that is, *study systematically*. While the ENCYCLOPEDIA will prove of the greatest value as a source of reference, particularly to men who have acquired a fundamental knowledge of mechanical subjects, the student who has no such foundation to build upon will obtain the greatest benefit from the ENCYCLOPEDIA if he starts with the fundamental principles as outlined in this GUIDE, proceeding in a systematic manner until he has mastered any one subject. By studying in this way, and devoting a certain amount of time each day or week to this work, greater benefit will be obtained from the ENCYCLOPEDIA than if first one article and then another on a different subject is read without following a definite plan. This method of reading is of value only when the student has a sufficiently broad foundation upon which to build, to permit him to add to the structure of knowledge in this manner. In reading the ENCYCLOPEDIA, however, on certain subjects, the man who is interested in the practical applications of certain machines and devices, rather than in their design and calculation, may pass by sections or paragraphs dealing with formulas or calculations only, which would not be useful in his work. Nothing would be gained by merely reading such sections without understanding them; but this is no modification of the rule that every subject should be studied systematically. If this general advice is followed, and particularly if a point is made of devoting certain hours to study, one may, within a comparatively short time, store up a considerable amount of general and special knowledge. After a while, systematic study becomes a habit, the mental capacity increases, the ability to grasp and understand mechanical subjects is developed, and study becomes no longer a tiresome effort.

Courses in Mechanical Engineering. — The different courses outlined in the GUIDE, taken together, form a most complete and practical course in mechanical engineering. To study all of these courses, however, would be too great a task for most men, and, therefore, it seems advisable to outline a few subjects that ought to be studied by every student of mechanics, in addition to the particular subjects in which he may be most interested. Every man engaged in mechanical work should learn the rudiments of mechanical drawing so that he can "read" drawings and sketches without difficulty. Drawing is a universal language, and the mechanic who does not understand the first principles of making drawings encounters many difficulties. A sketch tells much that cannot be described in words. It is almost as impossible for a man engaged in mechanical pursuits to succeed, if he does not understand mechanical drawing, as it would be if he could not read or write.

Any man who aspires to become a draftsman or designer — and a great many young shop men have this aspiration — should understand that the practical courses in mathematics and elementary theoretical mechanics outlined in this GUIDE are essential, and these courses, in connection with a study of the principles of machine design, constitute the foundation upon which a broad engineering education may be built; but, without this foundation, the designer will constantly meet with difficulties and find serious limitations in his efforts to succeed.

Elementary and Advanced Subjects Included. — The elementary side of mechanics and the broad principles which constitute the foundation for the science of engineering are included in the ENCYCLOPEDIA, together with the more advanced and special subjects, so that a man whose education is limited largely to practical experience may begin at the beginning and advance until he has acquired a general mechanical knowledge. To use a mechanical expression, the ENCYCLOPEDIA is "self-contained," in that many sections or subjects which might prove complex and difficult may readily be understood if the student will first refer to some other section, or, perhaps, a series of articles, which explain the rudiments of that subject.

Within the six volumes of this ENCYCLOPEDIA will be found a vast number of thorough treatises on almost every branch of mechanical work. These treatises or articles are like a series of small text-books, which deal with each subject separately and include only the most essential facts; they are intended primarily to give the student of mechanics and engineering a broad general knowledge of fundamental principles, and of tested and approved practice in the most important divisions of the engineering and manufacturing fields. The men who design, construct, and operate various classes of machinery need information that is fundamental and capable of general application.

As machines, in general, are devices for transmitting energy and motion from some source of power to a point where that energy and motion can be utilized, men seeking a broad mechanical education are interested in knowing what materials are used in machine construction; how iron and steel are produced from the ore; how castings, bars of stock, sheet metals and tubes are made; how the proportions of various parts are determined so that they will resist all stresses without danger of breakage; what tools and machines are adapted for cutting and finishing metal parts under different conditions, and how they are used; how power for driving machinery is generated, and how it is transmitted and controlled; and what principles govern the design of gearing and other important machine parts. All of these subjects and a great variety of others pertaining to the fundamental side of mechanics and engineering are dealt with.

Unit System of Arrangement. — In studying many of the subjects included in the ENCYCLOPEDIA, a guide would not be necessary, because all of the information may be found in one place, arranged in logical order. In a work of this kind, however, it would be impossible to deal with every subject in this way without a great deal of unnecessary repetition. Many of the larger subjects have been divided and subdivided, so that one may refer to, or study, the different branches separately. With this arrangement, definite information may readily be obtained without searching through a mass of text which might not be of interest to experienced men who use the work largely for reference purposes. For instance, take the subject of gearing. Each type of gearing is not only dealt with separately, but there are also independent articles on gear-cutters, gear-cutting machines, the heat-treatment of gears, gear-tooth grinding, and gear-tooth chamfering. The definite and important facts relating to each subdivision of a general subject are all in one place, and it is not necessary to collect them by extensive reading and research; that work has been done, so that the student, mechanic, or engineer may avoid unnecessary waste of time.

Theory versus Practice. — Some users of the ENCYCLOPEDIA, whose work has been largely in the shop, may consider these volumes too theoretical, because they contain here and there formulas which require for their use and solution a greater knowledge of mathematics than many shop men possess. It may, therefore, be well to mention here that throughout the ENCYCLOPEDIA all theoretical discussions that do not have a direct practical application have been excluded, and also that a majority of the formulas used are so simple that any man who knows ordinary arithmetic, and who will devote an hour or two to the article on Formulas (Vol. III, p. 201), will be able to make use of most of the formulas in the ENCYCLOPEDIA.

Many mechanics seem to have the idea that theory and practice are opposed; they refer to the words "theory" and "practice" as if they represented principles that are antagonistic to each other. Some, evidently, believe that a clearly defined line may be drawn between the territories of theory and practice, and the expression "right in theory but wrong in practice" is not at all uncommon. This attitude is erroneous. In the first place, there is no well-defined line between theory and practice, and there are many cases where the theory of yesterday is the practice of today. High-speed steel was a theory once; no man would call it a mere theory today. All great inventions were, at first, a theory. Properly defined, theory is simply an analysis of the laws which must be followed in practical work, if that work is to be correctly carried out; and practice simply means the application of theory to the work done. Theory is common sense logically applied, and practice is the use of theory in productive work. In the second place, theory and practice never disagree; if they do, then either the theory is incorrect, in which case it ceases to be acceptable, or the practice is wrong, and it should be corrected to agree with the theory. While it is true that theory without practice would be useless, so practice without theory becomes next to useless, because it implies only the crudest form of unskilled labor; and, without theory, invention and industrial development become impossible. Theory and practice belong together just as the work of the brain supplements that of the hand. No man ever works entirely by his brain, just as no man ever works entirely by his hands. Brain and hands cooperate constantly, although in different degrees; so also do theory and practice, and when the theory is correct, the more of it that is used in practical work, the better the results, because *nothing is more practical than correct theory.*

Specializing in Mechanical Work. — Successful specialists in mechanical work not only know their own work, but have a general knowledge of other branches bordering on, or closely allied to, their own work; in fact, specialization usually means the ability to focus on one line of work a general fund of knowledge. For instance, the man who is an expert in originating mechanical devices has, as a rule, developed his inventive faculties by studying the details of various classes of machines and mechanical movements. This is also true of the expert tool designer, who is an expert because he possesses a broad knowledge of general manufacturing requirements. A competent machine designer must know not only how to build a machine on paper, but must possess a general knowledge of machine manufacture. The experienced designer must understand the work which is to be done in the pattern shop, foundry, machine shop, and tool-room, in producing the machine or mechanism he has drawn on paper. Machine design involves not merely the designing of a machine that will perform the necessary work, but it is of great importance to so arrange and shape the different parts that the work of manufacture is not only practicable, but capable of being done on an efficient basis. In conjunction with the different courses of study outlined, the attention of the student is, therefore, directed to all important subjects which are indirectly related to the main subjects.

Supplementary Studies. — A very broad general mechanical education is obtainable by studying the ENCYCLOPEDIA systematically. Nevertheless, the student might profitably supplement some of the courses outlined in the following pages by reading other books which deal specifically with subjects in which he is especially interested in greater detail than is possible in a general work of this kind. The technical journals will also prove valuable as a source of information, especially on the developments which are constantly made in the engineering field. In the ENCYCLOPEDIA, many mechanical details subject to constant changes and of relatively little importance to a man seeking a general mechanical education, are purposely omitted. This point may be illustrated by reference to the subject of machine tools, as that class of metal-working machinery is dealt with in the ENCYCLOPEDIA. The various types of machine tools are described in a general way, and their uses explained. There is also a great deal of information on the exact method of handling various standard machine tools when applied to different classes of work. It was not considered advisable, however, to cover, in the descriptions of various machines of this class, all of the small details or the exact arrangement of every part. Such information, while important to the designer of that particular class of tools, would soon be out of date. The student who desires such detailed information should obtain it from technical journals covering the latest developments in his field.

The Opportunity for Self-education. — The man who uses the ENCYCLOPEDIA for the purpose of study should remember that it deals primarily with information that is fundamental and capable of general application in the engineering field. The machinist, toolmaker, foreman, or designer who appreciates the present-day requirements in the shop and drafting-room is not content with a one-sided experience and a mechanical education which is bounded by his own limited observations. He knows that it is essential to profit by what others have learned. The opportunity for doing so is presented to him by the ENCYCLOPEDIA, which records thousands of facts that are essential and of practical value.

The fact that a young man has had no opportunity to acquire a college, or even a good general school, education is not a bar to his success, provided he possesses the basic personal qualities of industry and application, in which case he can obtain an education by studying in his spare time. As a matter of fact, men successful in engineering generally acquire a very large share of their education in this manner, no matter what their general educational opportunities have been. No one engaged in mechanical work should feel satisfied until he has learned how to derive knowledge from the experiences of others, as recorded in books or periodicals, nor should he cease to keep himself informed about the latest developments in the field to which he has devoted his life. The man who has formed the habit of study not only understands his own line of work, but is able to apply himself to a larger field, if this is necessary for his future progress, and the best advice that can be given to young men who own the ENCYCLOPEDIA is to select some one subject in this GUIDE and begin an orderly and systematic course of study; the subject selected should be one that is simple enough to be readily understood, and one which, therefore, will act as the corner stone of a foundation which finally will support the entire educational structure.

MATHEMATICS

MATHEMATICS may be said to be the foundation of all engineering. Without the aid of the processes of arithmetic, even the simplest mechanical work could hardly be done; and in the design of machinery, and still more in the design of great engineering structures, calculations of a more or less advanced kind become absolutely necessary. An encyclopedia devoted to engineering work, therefore, must necessarily deal to a considerable extent with those mathematical processes and methods that are most commonly used by the practical mechanic and engineer.

Arithmetic. — Just as mathematics is the basic science underlying engineering, so arithmetic is the basis of all mathematics. It is, however, not the object of the ENCYCLOPEDIA to deal with the simple arithmetical processes, because these would naturally be too elementary for the class of readers for whom the ENCYCLOPEDIA is intended. There are, however, a number of subjects that come within the boundaries of arithmetic that may well have a place in any reference work of this kind, and for that reason brief articles have been included on such subjects as FACTORS (Vol. III, p. 94); SQUARE ROOT (Vol. V, p. 519); CUBE ROOT (Vol. II, p. 274); PROPORTION (Vol. V, p. 177); ALLIGATION (Vol. I, p. 65); PERCENTAGE (Vol. V, p. 3); INTEREST (Vol. IV, p. 71); ANNUITIES (Vol. I, p. 101); SINKING FUNDS (Vol. V, p. 367); and ARITHMETICAL PROGRESSION (Vol. I, p. 124). To those who use the ENCYCLOPEDIA as a reference work, these articles will be found useful, because they present each of these subjects in a brief and direct manner; to the student, they will be found complete enough for a comprehensive conception of the subject, provided he has a good knowledge of ordinary simple arithmetic.

Formulas and Diagrams. — With few exceptions, all the mathematics included in the ENCYCLOPEDIA can be used by anyone who thoroughly understands arithmetic, because, while formulas have been freely used, the majority of these formulas should present no difficulty to anyone versed in the elementary studies of mathematics. In order, however, that those who do not fully appreciate the simplicity of the use of formulas may be able to find in this work the instruction necessary on this subject, an article on FORMULAS, Vol. III, p. 201, has been included.

Closely allied to the use of formulas is the use of *diagrams*. Formulas record a mathematical statement by means of symbols or letters, while a diagram records a similar relationship graphically, by means of lines. Many mechanical men regard diagrams as something difficult to understand. This, however, is not the case, and, by a careful reading of the article on DIAGRAMS, Vol. II, p. 305, those not familiar with their interpretation will appreciate the great ease with which they can be used, and will be able to obtain the fullest value from such diagrams as are included in other sections of the ENCYCLOPEDIA.

In mathematics, a number of abbreviations, signs, and symbols are also used, and it is of considerable value to the man who reads mechanical literature, and occasionally meets with formulas, to memorize the commonly used signs and abbreviations. For this reason, a very complete collection of these has been given in the ENCYCLOPEDIA under the headings ABBREVIATIONS (Vol. I, p. 1); SIGNS (Vol. V, p. 365); and SYMBOLS (Vol. VI, p. 178). Any student of mechanics should carefully commit these to memory before going any further in his studies. It will facilitate his progress to a considerable extent and make it possible for him to grasp immediately the meaning of a formula which otherwise would be obscure.

Advanced Mathematical Course. — The engineer who has studied mathematics often finds it necessary, in the more advanced branches of the science, to refresh his memory in regard to such subjects as logarithms, algebra, geometry, or the solution of triangles. In fact, it would not be possible for a practical engineer to carry in his memory all the different formulas that are required. Hence, he will find extended use for a reference work which gives briefly the principal formulas and laws relating to these branches of mathematics; and the articles in this work relating to these sections of mathematics have been prepared to meet the needs both of the technically trained men, who would use the ENCYCLOPEDIA for reference, and the student who would use it to obtain a working knowledge of mathematics. While it is not intended that the ENCYCLOPEDIA should entirely supplant the need of text-books on mathematics, it does contain enough information on any one of the more important subjects of value to a practical engineer to enable him to obtain a working knowledge from the articles presented. For this reason, anyone who wishes to advance beyond the simpler arithmetical processes may profitably study the sections on LOGARITHMS (Vol. IV, p. 240); EQUATIONS (Vol. III, p. 67); ALGEBRA (Vol. I, p. 60); MENSURATION (Vol. IV, p. 336); GEOMETRY (Vol. III, p. 407); and TRIGONOMETRY (Vol. VI, p. 324).

Logarithms. — Logarithms, Vol. IV, p. 240, present a means whereby certain arithmetical calculations, especially those involving multiplication and division, may be carried out much more rapidly than they could be by ordinary arithmetic. The methods used are simple, but require the use of logarithmic tables. These tables are not included in the ENCYCLOPEDIA, as they do not belong in a work of this kind, but they are easily obtainable from any publisher of mechanical books. The use of logarithms also facilitates, in a great degree, calculations involving interest, annuities, and sinking funds; and in machine design the calculations required for arranging the speeds and feeds of a machine tool in geometrical progression require the use of logarithms. An article is also included on GEOMETRICAL PROGRESSION, Vol. III, p. 406, and the application to practical problems is illustrated by examples in the article on MACHINE TOOL DRIVES, Vol. IV, p. 270.

Algebra and Equations. — Algebra is a subject which makes it possible to easily make calculations in machine design which otherwise — by means of arithmetic only — would be very lengthy and cumbersome. In algebra, letters are used to signify numbers, making it possible to carry out many calculations with great rapidity. The principal laws and methods of algebraic calculations are explained in a simple manner in the article on ALGEBRA, Vol. I, p. 60. Algebra is especially valuable in its application to the solution of equations, by means of which problems in machine design, or in any kind of mathematics, are frequently solved with much greater ease than in any other way. Equations may be termed a special kind of formulas; they can generally be solved without recourse to any other mathematical knowledge than that of arithmetic, provided a few simple principles are understood. These are explained in the section on EQUATIONS, Vol. III, p. 67, and, for practical purposes, the information there given will be found sufficient.

Areas and Volumes. — The calculation of areas and volumes is generally included, mathematically, under the head *mensuration*. This part of mathematics deals with the finding of the areas of triangles, squares, circles, etc., and the volumes of solid bodies, such as cubes, cylinders, cones, and spheres, and parts of these solid bodies. In the section on MENSURATION, Vol. IV, p. 336, in the ENCYCLOPEDIA, a very complete collection of formulas is given, covering practically all geometrical surfaces and solid bodies that would ever be encountered in engineering work. Examples of the use of the formulas given are presented in each case, so that there will be no doubt as to their application. This section will, therefore, be found useful both for rapid reference and for the purposes of study. The mensuration of regular polygons is dealt with more completely in the article on POLYGONS, Vol. V, p. 127, and those interested in the study of the complete subject should also refer to that article.

Solution of Triangles. — Trigonometry, Vol. VI, p. 324, may be considered as a special subdivision of mensuration. This part of mathematics deals particularly with the solution of triangles — that is, the determination of the length of the sides, the angles, and the areas of triangles. There is probably no part of mathematics that is more useful or more frequently required in drafting or designing work than this. There is hardly a lay-out, either of tools, fixtures, or machine parts, if it is at all complicated, that does not require a calculation involving angles and sides of triangles. Every draftsman and designer must be familiar with the use of the formulas employed for the solving of triangles, and an understanding of the subject is also of great value to toolmakers and machinists. The subject is not difficult, and can be mastered in a few evenings of study. In calculations involving angles, tables similar to logarithmic tables are required. These tables are not included in the ENCYCLOPEDIA, as they are generally provided in books used for handy reference convenient to keep on the drafting-board or in the tool chest, and can be obtained from the publishers of mechanical books.

Geometry. — Geometry deals with the relations of lines and surfaces, and a conception of the fundamental geometrical propositions is very valuable to any mechanic, and absolutely necessary to a designer or engineer. In the article on GEOMETRY, Vol. III, p. 407, all the fundamental geometrical propositions are given and also the methods used for geometrical drawing. These latter, especially, should be familiar to every draftsman.

There are many still more advanced branches of mathematics, knowledge of which may not be considered absolutely essential to practical mechanics. Of these, analytical geometry, perhaps, is the simplest and most useful, and a brief article explaining the fundamental principles of this branch of mathematics has been included under the heading ANALYTICAL GEOMETRY, Vol. I, p. 91; but it is not possible nor desirable to deal completely in the ENCYCLOPEDIA with these more advanced branches of mathematics, as the student who wishes to pursue mathematics as a science would necessarily have to be referred to works devoted exclusively to mathematics. The ENCYCLOPEDIA deals primarily with branches of mathematics that are of direct practical application in the mechanical trades, and, hence, the sections on mathematics have been limited to those considered directly useful to designers, draftsmen, toolmakers, and machinists in the machine-building field.

The Slide-rule. — In making calculations in the shop or drafting-room, the slide-rule makes it possible to save a great deal of time. The slide-rule is an instrument by means of which calculations involving a great deal of multiplication, division, etc., can be readily made by a simple setting of a sliding scale in relation to another scale. Many drafting-rooms require that every draftsman shall possess a slide-rule and know how to use it, and it is recognized as one of the most important of the tools of the engineer and designer. Even the toolmaker often can use the slide-rule to advantage, and shop executives — superintendents and foremen — would find that there are many calculations where the slide-rule would be very convenient to them. The slide-rule is simply a labor-saving tool; it performs in a few seconds the work that otherwise would take several minutes. It is not possible with the slide-rule to obtain absolute accuracy to more than three, or at most four figures, but there are many calculations in the shop and drafting-room that require no greater accuracy than this, and its general use is to be strongly recommended. For checking purposes, especially, it is of great value. The article on the SLIDE-RULE, Vol. V, p. 373, gives very complete information as to its use, showing by engravings the settings required for different kinds of arithmetical problems.

THEORETICAL MECHANICS

THE science of mechanics may be divided into two distinct parts — theoretical and applied mechanics. Theoretical mechanics deals with the fundamental principles and laws of the forces of nature; applied mechanics deals with the use and application of these laws and principles in the design of machinery and structures, and in the operation of various forms of mechanical apparatus. Every mechanic is familiar with the simpler principles of theoretical mechanics, although he may not be able to state them in exact words; but he knows them instinctively, because he applies them daily in his work at the machine or the bench, and his success as a mechanic depends largely upon the degree to which he recognizes these principles, even if he does not understand or formulate them in his mind. When, as a designer, he attempts to create in his mind and draw on paper mechanical devices, it becomes, however, necessary for him to fully understand these principles. The builder of machines who has a thorough grasp of the laws of mechanics will be more successful than the man who has not studied this subject; he will make fewer mistakes and avoid many of the pitfalls into which the practical man who builds solely on past experience, without an understanding of theoretical principles, is liable to fall. Many inventors have wasted a great deal of their time and energy on impossible combinations of machine details or on impractical devices, such, for example, as perpetual motion machines, simply because they did not understand the primary laws of mechanics. Every practical mechanic will become a better and more successful man in his trade by understanding these fundamental principles. There is nothing difficult about theoretical mechanics to anyone who has a good knowledge of arithmetic and understands the use of formulas, a subject which is very simple, and which is explained in the section on FORMULAS, Vol. III, p. 201. With a grasp of these subjects, the articles on theoretical mechanics in the ENCYCLOPEDIA will be found clear and simple.

Arrangement of Course in Mechanics. — The various subjects that come under the head of theoretical mechanics will be found in the ENCYCLOPEDIA in separate sections or articles, making it easy for the man who uses the work for reference only to find directly the subject in which he is interested. The student, however, who is anxious to cover the subject in the form of a course will need some directions in order to obtain the full benefit from the material contained in the ENCYCLOPEDIA. To obtain a general survey of the subject, he would first study the section on MECHANICS, Vol. IV, p. 329, which deals briefly with forces, work, power, moments, mechanical powers, gravity, friction, motion, mass, energy, and centrifugal force, all of which subjects comprise the fundamental principles of the science of mechanics. This article, in fact, would give the shop man who does not need to study the subject as deeply as would a machine designer, a general conception of mechanics. The machine designer, however, would need a more thorough understanding of the subject, and would have to turn to the detailed articles which treat more completely with each phase.

Principles of Force, Work, and Power. — While the elementary principles involved in the mechanical conceptions of force, work, and power are explained briefly in Vol. IV, pp. 329 and 330, a more complete article dealing with the principles and laws involved in the application of forces will be found under the heading FORCE, Vol. III, p. 173. When a force performs work for a given time it produces power, and power, in the mechanical sense, is most commonly measured in HORSEPOWER (Vol. IV, p. 31) and KILOWATT (Vol. IV, p. 154). There are also other units in which power may be measured, and a comparison of all these units is given in the article on POWER AND HEAT EQUIVALENTS, Vol. V, p. 129. The power developed by a power-producing machine may be measured by a DYNAMOMETER (Vol. II, p. 513). Many a practical man is often confused when reading mechanical books or journals, because he lacks a thorough understanding of the expressions force, work, and power, as used in their mechanical sense. A study of the articles referred to, which would occupy only an evening or two, in order to fully master the subject, would greatly increase his ability to benefit from the reading of other mechanical literature. The use of the ENCYCLOPEDIA would also be greatly facilitated by the understanding of these primary terms so frequently used in mechanics.

Moments and Mechanical Powers. — Among the very important fundamental principles of theoretical mechanics is that known as the "principle of moments." This principle enters in one way or another into the design of practically every device and machine and is highly important in all constructions that involve the use of levers. The principle of moments is explained in the general article on MECHANICS, in a section headed *Moments* (Vol. IV, p. 330). The specific application of moments to levers of different kinds, and a practical example showing the application of levers in the design of a platform scale, which is one of the most complicated and important arrangements in which a knowledge of the subject of leverage is absolutely necessary, is given in the article headed LEVER, Vol. IV, p. 201. The lever is one of the so-called mechanical powers, or simple devices, by means of which the effect of a force is multiplied. These mechanical powers, besides the lever, are known as the *wheel and axle*, the *pulley* (and its practical application in the "block and tackle"), the *inclined plane*, and the *screw*. A review of the fundamental principles embodied in all the mechanical powers is given in Vol. IV, p. 331, and the principles and formulas applicable to each are given in greater detail in the separate articles on BLOCK AND TACKLE (Vol. I, p. 382); INCLINED PLANE (Vol. IV, p. 46); SCREW (Vol. V, p. 323); and WHEEL AND AXLE (Vol. VI, p. 503). An understanding of the principles here outlined makes it possible to determine exactly the amount of power required for performing mechanical work in machines and devices that employ directly, or with modifications, the simple devices known as "mechanical powers."

Center of Gravity and Specific Gravity. — Another important section of theoretical mechanics is that which deals with the attractive force between the earth and bodies on or near its surface, and which is known as "gravity." Gravity manifests itself in the weight of bodies, and as weight is one of the important factors to be reckoned with in the design of machinery and structures, and in the operation of machinery as well, the mechanical laws dealing with gravity are highly important. The elementary principles are dealt with in Vol. IV, p. 331. The center of gravity, or the point at which the weight of a body may be considered as concentrated as far as mechanical calculations are concerned, is of importance in the design of moving machine parts and also in the calculation of the strength of beams subjected to bending. Formulas giving the location of the center of gravity of practically all surfaces and solids of ordinary geometrical shape are given in the article headed GRAVITY, CENTER OF (Vol. III, p. 429). The specific gravity or the weight of a material compared with the weight of an equal volume of water is also of importance in the calculation of the weights of any material the volume or dimensions of which are known. The article on SPECIFIC GRAVITY, Vol. V, p. 398, contains extensive tables giving the specific gravities of a great many metals, woods, and other materials, as well as of liquids and gases. In the case of a gas, the specific gravity means the weight of a certain volume of the gas compared with the weight of an equal volume of air. In the article mentioned, methods of calculating weights when the specific gravity is known are explained, as well as methods used for obtaining the specific gravity of a sample of a metal or alloy. The principle of specific gravity was first expressed by Archimedes, a Greek philosopher, and is known as the ARCHIMEDIAN PRINCIPLE, Vol. I, p. 124. The specific gravity of liquids cannot be determined in the same manner as that of solids, but simple devices known as HYDROMETERS (Vol. IV, p. 44) have been devised for finding the specific gravity of any liquid by merely immersing the instrument in the liquid.

Friction. — Friction is a subject with which every mechanic is in a general way familiar. Frictional losses in machine bearings are responsible for the loss of a great deal of the power supplied to a machine. In some instances, in fact, more power is consumed in overcoming frictional resistance than in performing useful work. Although the presence of friction is well known, the principles of frictional resistance are not well understood; in fact, there are some of the laws of friction that even the scientists have not as yet fully agreed upon. The elementary and well-known principles, however, are explained in the article on MECHANICS, under the heading *Friction*, Vol. IV, p. 331, and in greater detail in the article on FRICTION, Vol. III, p. 214, where the coefficients of friction for certain metals and other materials used in the construction of machinery and devices are given. Friction introduces the only uncertain element in theoretical mechanics. The forces acting and the results obtained in the case of levers, screws, and other mechanical powers could be determined with absolute accuracy were it not for the friction between the parts; but the coefficient of friction varies to a considerable extent according to the materials used, the conditions of the bearing surfaces, the amount of lubrication, and the kind of lubricant. Experiments, however, have been undertaken to determine as accurately as possible the effect of friction in different cases, and the results of these experiments are recorded in the article referred to in such a way that the designer or engineer may be able to determine within a fair degree of accuracy what the effects of friction will be in any particular case.

Laws of Motion, Velocity, and Mass. — The sections of mechanics so far dealt with are concerned primarily with the establishment of equilibrium between different forces, and these parts of the subject are generally combined under the name *statics*. Those parts of theoretical mechanics which deal with moving bodies are all included under the general heading *dynamics*. Dynamics deals with motion, and, in connection with motion, with velocity, the laws of falling bodies, inertia, energy, centrifugal force, and the movements of pendulums. The mechanics of moving bodies involve many new principles not considered when dealing with the mere equilibrium of forces. Many of the most difficult problems in machine design are due to the rapid motion of some machine elements, which introduces stresses in the machine parts that are not present when these parts move slowly or are at rest. In a flywheel, for example, the stresses increase with great rapidity as the speed is increased. Many fatal accidents have resulted from the failure of designers and operators to recognize or understand the forces that are at work in rapidly moving bodies. The study of motion, velocity, and centrifugal force, therefore, becomes of the greatest importance to anyone who designs machinery having rapidly moving parts.

A general review of the laws of motion will be found in the article on MECHANICS under the heading *Motion*, Vol. IV, p. 332, and a more complete treatise, giving the formulas required for different kinds of motion, in the article on MOTION, Vol. IV, p. 432. The first investigator of the laws of motion, who formulated the principles in a manner so accurate that they are accepted to this day, was Sir Isaac Newton. He formulated three laws of motion, which are given in Vol. IV, p. 333. In the study of motion, one of the most important factors to be considered is velocity, which may be either *relative* or *absolute*, as explained in the article on VELOCITY, Vol. VI, p. 436. In the case of rotating bodies, the velocity of motion is known as ANGULAR VELOCITY, Vol. I, p. 99. The laws of motion relating to falling bodies find application in a great many cases in practical mechanics. They underlie the motions involved in cranes and lifting appliances of all kinds, and are also of direct application in the case of power hammers and all machinery acting by blows rather than by steady pressure. The principles and formulas applying in this part of mechanics are given in the article on FALLING BODIES, Vol. III, p. 101. In connection with this subject, ENERGY, Vol. III, p. 57, and BLOW, FORCE OF, Vol. I, p. 392, should also be studied.

Centrifugal Force and its Applications. — There is perhaps no manifestation of the forces created by motion that is more apparent or well known than that of centrifugal force. Every mechanic, no matter what his occupation, knows that a rapidly revolving wheel or disk — a flywheel or a grinding wheel — is liable to burst in case the speed becomes too high. He may not know that the force tending to cause the grinding wheel to fly apart increases much more rapidly than the speed of the wheel, but he knows that such a force exists. The machine designer who deals with rapidly revolving machine parts must, however, know not only that the force exists, but also how great that force is, so that he can guard against the dangers due to the bursting of rapidly revolving flywheels, pulleys, or similar machine parts. The stresses can be accurately calculated by formulas that give very exact results. This subject is dealt with in the article on CENTRIFUGAL FORCE, Vol. II, p. 43. The influence of the laws of centrifugal force on the design of flywheels is probably the most common application in practice. This is dealt with in the article on FLYWHEELS, Vol. III, p. 160. Another application is met with in governors of steam engines, Vol. VI, p. 18. An application of forces due to rapid rotation is also met with in the GYROSCOPE, Vol. III, p. 490.

The moment of inertia of rotating bodies is a mathematical quantity which is used in certain mechanical calculations; formulas for the moment of inertia in relation to solid bodies are given in the article INERTIA, MOMENT OF, Vol. IV, p. 57. The moment of inertia with relation to surfaces is not employed directly in theoretical mechanics, but is of very great importance in applied mechanics, when dealing with the strength of materials in the calculation of beams subjected to bending stresses. The moment of inertia for surfaces, therefore, is given in the article on BEAMS, Vol. I, p. 264. The polar moment of inertia is also used in connection with the strength of materials of shafts or other bodies subjected to torsional or twisting stresses; information on this subject is given in STRENGTH OF MATERIALS, Vol. VI, p. 95.

Simple, Compound, and Conical Pendulum. — Some of the most interesting of the laws of theoretical mechanics are those dealing with the pendulum. They do not have so general an application to machine design and practical mechanics as have the other laws just mentioned. Nevertheless, they are of the greatest importance in their relation to our daily life, because it is the pendulum that provides a means of exactly measuring time, the pendulum of clocks being proportioned accurately according to calculations and measurements based upon theoretical laws that have been precisely determined. These laws are given in the article on PENDULUM, Vol. V, p. 2. The simple pendulum is a mere theoretical conception, it being defined as a point having weight only, suspended by a weightless cord. Apparently such a condition can only be approximated in practice. The compound pendulum is the one which finds its practical application in clocks. The conical pendulum, again, finds extensive application in the design of governors for steam engines, and is also used in speed-regulating devices for other machinery, the form of governor based upon the conical pendulum being known as a "fly-ball" governor. This type of governor is described in Vol. VI, p. 18, and the formulas required for its calculation are given in Vol. V, p. 3.

Mechanics of Fluids and Gases. — The science of mechanics may be considered as divided into three sections — the mechanics of solids, of fluids, and of gases. Generally speaking, the man engaged in mechanical pursuits has mainly to deal with the mechanics of solids. In the design of such machines as pumps, hydraulic presses, and water-wheels and turbines, he must, however, also deal with the mechanics of fluids, and in the design of steam and gas engines, air compressors, and pneumatic machinery, with the mechanics of gases. In the ENCYCLOPEDIA, the mechanics of fluids has been dealt with briefly in the article WATER, PRESSURE AND FLOW, Vol. VI, p. 443, and in its application to the different kinds of hydraulic machinery mentioned, in the articles on HYDRAULIC PRESSES, Vol. IV, p. 34; PUMPS, Vol. V, p. 183; and WATER-WHEELS AND TURBINES, Vol. VI, p. 444.

In dealing with the mechanics of gases, the practical mechanic is mainly interested in air and steam. The two important properties of gases are their pressure and flow. As an introductory article, that on PRESSURE, Vol. V, p. 164, may be studied. The properties of air are dealt with in the article on AIR, Vol. I, p. 27. The compression of air follows certain very definite laws and principles, which are dealt with in AIR COMPRESSION, Vol. I, p. 30, and in the first paragraphs of AIR COMPRESSORS, Vol. I, p. 31. The properties of steam may be studied from the paragraphs on this subject beginning on page 419, in Vol. I, in the article on BOILERS. The action of steam in a steam engine is dealt with in the article STEAM ENGINES, Vol. VI, p. 1. The properties of superheated steam are dealt with separately in the article SUPERHEATED STEAM, Vol. VI, p. 122.

Heat and Temperature Measurements. — The subject of heat is closely allied to that of mechanics. An understanding of the elementary principles relating to the subject of heat is, therefore, of value to anyone engaged in mechanical work. Heat plays an important part in a great many of the machines used for power production or transmission. The designer of air compressors, steam engines, boilers, steam turbines, gas engines, and many other machines must have an understanding of the principal laws of heat transmission, radiation, insulation, etc. The ENCYCLOPEDIA, therefore, deals with this subject in such a manner that the student may obtain a brief, but satisfactory, review of this branch of physical science. The article on HEAT, Vol. III, p. 541, deals with the subject in a general manner, and the articles on LATENT HEAT, Vol. IV, p. 169, and SPECIFIC HEAT, Vol. V, p. 401, give tables relating to the latent heat and specific heat of various substances. The amount or quantity of heat is measured in certain units known, respectively, as *British thermal units* and *calories*, these units being defined and their equivalent values given in the article on HEAT (Vol. III, p. 541). In thermochemistry, quantities of heat are measured in OSTWALD CALORIES (Vol. IV, p. 509). The specific heat of bodies, and quantities of heat generally, are measured by the aid of CALORIMETERS, Vol. I, p. 529.

All solid bodies will be transformed into liquids and all liquids into gases if sufficient heat is applied to them to raise the temperature to the melting or vaporizing point. The melting points of metals, and also of a number of metal alloys, are given in the article MELTING POINTS OF METALS, Vol. IV, p. 334. The vaporization points of the more important metals are given in connection with the articles on the respective metals.

In order to prevent heat from escaping from a surface — a cylinder, pipe or other part of a machine depending upon heat for its proper function — heat-insulating materials are used. The value of different kinds of heat-insulating materials and their application are dealt with in the article on HEAT-INSULATING MATERIALS, Vol. III, p. 542.

MECHANICAL TRANSMISSION OF POWER

ANY machine or mechanical apparatus equipped with moving parts may be defined as a device for transmitting energy derived from some source of power to a place where work is to be performed. In the construction of any such mechanical apparatus, there are two important and fundamental points to be considered. In the first place, it is necessary to so design the machine that the necessary motion will be obtained; second, the combination of parts forming the machine must be so proportioned that the energy or power may be transmitted without breakage or excessive distortion of the parts. In the design of any machine, then, it is necessary to consider the practicable methods of transmitting motion from one machine part to another, and to analyze the magnitude of the forces that are to act upon the mechanism.

The object of the course of reading and study outlined in the following paragraphs is to give the student a general idea of the methods of transmitting power under different conditions, or the means of obtaining the right kind of motion or of modifying it to suit specific purposes, without considering, at present, the forces which are to act upon the machine parts or the proportioning of these parts with reference to their strength. In some cases, the sections or articles referred to deal with problems in design, but students not familiar with mechanical details should defer studying the sections treating exclusively on design, in order to first obtain a general knowledge of the practical means of transmitting motion. The proportioning of machine parts will be dealt with later under " Principles of Machine Design."

General Methods of Power Transmission. — The form of mechanism utilized to transmit motion from one machine part to another part is governed by the motion of the driving member, the kind of motion to be imparted to the driven member, the distance between the driving and driven members, their position relative to each other, and the amount of energy or power to be transmitted. A plain shaft which serves to transmit motion from one part or combination of parts to another represents a direct form of power transmission. The flexible shaft is a form of transmission that has been extensively used when the driven member must have a free or universal movement. Among other forms of transmission may be mentioned the various applications of link and lever mechanisms, including straight line motions, toggle joints, etc.; the use of frictional gearing and various forms of toothed gearing; the transmission by belts or by means of rope or chain drive; the use of cams, especially when a complex or irregular movement is required; and the use of the screw, which might be classified as a type of cam having a working groove of helical form.

Solid and Flexible Shafting. — While shafting may be considered as a means of transmitting power, as previously mentioned, it is also used for supporting various kinds of power transmitting devices, such as pulleys, gears, cams, sprockets, etc. The article on SHAFTING, Vol. V, p. 331, deals principally with the stresses to which shafts are subjected and the proportioning of shafts to safely withstand these stresses. Therefore, this article is of especial value in the general study of machine design, although it contains some information that might well be included in a general course of reading featuring particularly methods of transmitting power.

Flexible shafting which consists of a flexible core that is arranged to revolve within an outer casing is often used when the driven member must have a free movement. (See FLEXIBLE SHAFTING, Vol. III, p. 156.) COUNTERSHAFTS, Vol. II, p. 225, are short shafts used in shops and factories having belt-driven machines for stopping or starting machines independently, and in some cases for obtaining speed variations.

Link and Lever Mechanisms. — A link may be defined as a rigid body for connecting parts of a machine or mechanism, and its functions may be either to transmit motion or to support or guide some member or combination of parts. Many machine parts which belong to the general class designated as "links" are given special names. For instance, if a link has a swinging or oscillating movement about a pin or fulcrum, it is usually known as a "lever" or "rocker." If a link makes complete revolutions, it may be known as a "crank," and a link which transmits motion from a revolving crank to a part having a straight-line motion is classified as a "connecting-rod" or "pitman." The side rod on a locomotive, which connects the main driving wheel with all the other drivers, is another application of a link. Throughout the ENCYCLOPEDIA there are a great many illustrated descriptions of different designs of machines and devices which include link and lever mechanisms. When reading descriptions of machines of different classes, it is advisable to note details of this kind, in order to see how and when various types of link mechanisms are applied. The article on the LEVER, Vol. IV, p. 201, contains information of an elementary nature on this simple, but very important, machine element. WHITWORTH MOTION, Vol. VI, p. 504, is a form of link mechanism that has been extensively used to obtain a quick-return motion, especially on machine tools of the slotter class. The PEAUCELLIER MOTION, Vol. V, p. 1, is another example of a link mechanism which is commonly classified as a straight-line motion, because it consists of a combination of links so arranged that a rectilinear motion is obtained independently of guides or ways.

The well-known pantograph mechanism is a form of link mechanism intended especially for reproducing a motion on a reduced or enlarged scale. The most important practical application of the pantograph is found on engraving machines (see Vol. III, p. 58). Another important link mechanism which applies to certain types of machines, such as drawing and embossing presses, stone crushers, etc., for obtaining great pressure, is known as the TOGGLE JOINT, Vol. VI, p. 292. In view of the fact that motion, in a great many cases, is transmitted through a train of mechanisms or combination of parts, many of the designs referred to in connection with other classes of transmission devices will illustrate various applications of links and levers.

Transmission by Frictional Gearing. — When rotary motion is to be transmitted from one shaft to another, this may be done very easily by means of driving and driven members which are in contact and simply roll against each other, provided the shafts are not too far apart for this kind of drive, and the rolling or frictional contact will transmit the necessary amount of power. This kind of transmission, which is classified as frictional gearing, has been used quite extensively on certain classes of machinery, although it is not a suitable form of drive when it is essential to maintain a fixed relation between the driving and driven members throughout a cycle of operations. General information on this subject will be found in the article FRICTION WHEELS FOR POWER TRANSMISSION, Vol. III, p. 217.

Transmission by Spur Gearing. — When cylinders or cones which roll in contact with each other are used to transmit motion, slipping is liable to occur, especially if the amount of power transmitted is somewhat excessive for gearing of this type. Owing to the advantages of a positive drive, toothed gearing is used in one way or another on a large percentage of the machines of all classes. When shafts are parallel, some form of spur gearing is generally used. The general subject of gearing, including spur gears and the other types mentioned later, is one of great importance not only to students of machine design, but also to those interested in machine construction or shop practice. A simple explanation of the principles of spur gearing will be found in Vol. V, p. 501. It is recommended that the student read only that part of the article which deals with the subject in a general way, leaving the calculations used in spur gear design for future reference, as these should be taken up in connection with machine design. Internal gearing, which is simply a special form of spur gearing, is treated in Vol. IV, p. 75. While motion is generally transmitted between two shafts by using two gears only, in many instances it is necessary to transmit motion through three or more gears, which combination is known as a "gear train." The article on GEAR TRAINS, Vol. III, p. 386, explains the effect which such intermediate gearing has on the speed ratio, and how this ratio may be determined both for simple and compound gearing. If a gear train consists of a stationary gear about which another gear revolves in addition to rotating relative to its own axis, this combination is known as "epicyclic" gearing, and it is of particular value when a considerable reduction of speed between the driving and driven members is necessary. Owing to the combination of movements, it is rather difficult to determine the speed ratio of this gearing unless the action is analyzed in a methodical way. In the article on EPICYCLIC GEARING, Vol. III, p. 64, methods of determining speed ratios are described. Reference should also be made to the article on ECCENTRIC GEARS, Vol. II, p. 518, which deals particularly with the application of this type of gearing to automobile transmissions. Spur gears are ordinarily of circular form, but gears of elliptical shape have been used to a limited extent in order to accelerate the movement of the driven member during part of a revolution, the object being to obtain a quick-return motion. General information on elliptic gears will be found in Vol. III, p. 50.

Transmission by Bevel Gearing. — When two shafts are either at right angles to each other, or at an angle that is somewhat greater or less than 90 degrees, motion is commonly transmitted from one to the other through bevel gearing. The beginning of the section on BEVEL GEARING, Vol. I, p. 352, explains the general features of this type of gearing and its practical application. The axes of ordinary bevel gears lie in the same plane, but there is a special form known as "skew bevel gears," for connecting shafts which are not only at an angle to each other, but somewhat offset. (See SKEW BEVEL GEARS, Vol. V, p. 367.) The spiral type bevel gear (Vol. V, p. 470) represents another development used particularly on automobile transmissions. This gearing differs from the ordinary type in that the teeth are curved instead of being straight; for general information, see Vol. I, p. 367, in the section on BEVEL GEARING.

Spiral or Helical Gearing. — The type of gearing commonly known as "spiral" gearing, or, more properly, "helical" gearing, is generally used for transmitting motion between shafts which are not parallel and do not lie in the same plane, but also for connecting parallel shafts. The pitch surfaces or imaginary surfaces upon which the gears roll are cylindrical, the same as with spur gears, but the teeth follow helical curves like screw threads, instead of being parallel to the axis. (See SPIRAL GEARING, Vol. V, p. 461.) If the distance between the shafts or the planes in which the axes of the shafts lie is relatively small, it may be necessary to use skew bevel gears. When high speeds are necessary and smoothness of action essential, helical gearing is sometimes used for connecting parallel shafts. The general practice is to use a double helical gear, or one having both right and left-hand teeth in order to eliminate end-thrust. Such gearing is known as HERRINGBONE GEARS, Vol. III, p. 544.

Transmission by Worm Gearing. — Worm gearing is similar in principle to spiral gearing, a single-threaded worm being, in reality, a spiral gear having one continuous tooth. The particular advantages of worm gearing are in the smoothness of action and the possibility of obtaining a large reduction in velocity between a driving and driven shaft. This gearing is used in many forms of transmission in which steadiness of motion or a considerable change of velocity is necessary. The increase in effective power which may be obtained through this gearing is also a decided advantage for many purposes, and the gearing is self-locking, which is another valuable feature in connection with certain installations. (See WORM GEARING, Vol. VI, p. 541.)

Intermittent Gearing. — In certain classes of mechanisms, motion between a driving and driven member is not continuous but intermittent. Gearing of this type may be so arranged that the driven member is moved through part of a revolution each time the driver makes a complete turn, or the driven part may be given several impulses or movements for one revolution of the driver. Intermittent gears vary considerably in their design or form, modifications being necessary to suit different conditions. The article on INTERMITTENT GEARING, Vol. IV, p. 72, describes gears for various kinds of intermittent motion. Ratchet gearing may also be classified as a form of intermittent gearing and is extensively used on a great variety of machines and mechanisms. General methods of applying ratchet gearing are described in Vol. V, p. 232. The practical applications of some of the forms of ratchet gearing illustrated diagrammatically in connection with this article will be found on various tools and machines described throughout the ENCYCLOPEDIA.

Transmission by Belts. — When shafts are located too far apart for any form of gear transmission, it is common practice to connect them by means of a belt made either of leather, cotton, or cotton and rubber composition. The effectiveness of a belt as a transmitter of power depends upon several factors, such as the tension of the belt, the frictional resistance between the belt and pulley rims, and the amount of belt surface in contact with the rim. Many belt drives are very inefficient, either because the kind of belt in use is not adapted to the requirements or conditions under which it must operate, or because the belt is not properly installed and cared for. A general knowledge of the subject of belting and belt installation will prove useful to the machinist, shop foreman, or draftsman. A complete section on BELTING will be found in Vol. I, p. 318, covering the application of belts; the selection of belt stock; methods of joining belt ends by cementing and lacing; the causes of belt failures; the horsepower transmitted by belting; the installation of angular belt drives; and other general information of a definite and practical nature. While belts are still used very extensively and doubtless will continue to be, they have been either partly or entirely replaced in many machine shops and other plants or factories by motor-driven machinery. The subject of motor drive will be considered later. In connection with the subject of belting, reference should be made to the article on PULLEYS, Vol. V, p. 180; PULLEY SPEEDS, Vol. V, p. 182; and TENSION SCALES FOR BELTS, Vol. VI, p. 223.

Chain Type of Transmission. — When the center-to-center distance between driving and driven shafts is too great for gears, but too small for an ordinary belt drive, a chain transmission is commonly used, especially if a positive drive is necessary, or there is considerable power to be transmitted. A chain drive is practically a belt composed of chain links which engage projecting teeth on the rims of sprocket wheels that take the place of smooth-rimmed pulleys, such as are used with ordinary belt drives. There are several distinct types of transmission chains on the market which are intended for different classes of service and vary considerably in cost. Some of the cheaper grades are preferable to the more expensive types when used on classes of work for which they are primarily intended. When installing a chain transmission, it is important to select a chain of the right type, to use sprocket wheels having teeth of the proper shape, and to provide for operating the chain drive at a speed regulated in accordance with the type of chain. The section on CHAIN TRANSMISSION, Vol. II, p. 60, covers these and many other important points related to the selection of chain drives, their design and installation, and the cutting of the teeth of sprocket wheels.

Transmission of Power by Rope. — Rope has been used in many factories and mills for transmitting power from the power plant to different lines of shafting, although this type of transmission has been replaced to a considerable extent by electrical equipment. The rope used may be made of hemp, cotton, or wire. General information on the American and English systems of rope transmission, and data relating to the design and installation of rope drive, will be found in the section on ROPE TRANSMISSION, Vol. V, p. 292. When ropes are used to transmit continuous rotary motion by operating over pulleys, it is essential to have the rope ends properly spliced or joined together. The methods of splicing Manila and wire transmission ropes are explained in the article on ROPE SPLICING, Vol. V, p. 289.

The section on rope transmission referred to pertains especially to the use of ropes for transmitting continuous rotary motion from one shaft to another. The most extensive use of ropes, however, as a means of transmitting motion from some source of power to a driven member, is in connection with various classes of hoisting and haulage apparatus, such as cranes, mine hoists, elevators, tramways, etc. For this class of service, some kind of wire rope is generally used. The section on WIRE ROPE, Vol. VI, p. 520, describes various classes of wire rope, their properties, range of application, strength, etc.

Motion from Cams. — Most of the wonderful automatic machines now used so extensively and for such a variety of purposes derive their intricate movements from various forms of cams. Every man who has a natural bent for mechanics finds something fascinating about an automatic machine. Take, as an example, a modern automatic screw machine. It seems more like a living thing than a machine, with a mind that controls its actions. The rough stock is gripped by the chuck and drawn inward; the tools advance and recede; another set of tools comes into action; and every few seconds a finished piece is severed from the rough bar. Practically all of these intricate motions are derived from cams. In fact, without the aid of cams, many of the complex movements that are essential to the operation of various classes of automatic machines would be impossible to obtain; therefore, the subject of cams is of vital importance to every draftsman and designer, as well as to those interested in invention, especially if irregular and intricate motions are involved. The exact movement derived from any cam depends upon the shape of its operating groove or edge, which must be designed according to the motion required. It is also necessary to vary the general shape of the cam in accordance with the relative movements of the cam and its follower. The section on CAM DESIGN, Vol. I, p. 530, covers different classes of cams, simple methods of laying out cams to obtain different motions, and other general information.

Mechanisms for Varying Speed. — In the operation of many different classes of machinery, it is necessary for one reason or another to change the speed of a driven member. A feature of this kind is of especial importance on different classes of metal-cutting machines, in order to vary the speeds and feeds for different kinds of metal and when operating under different conditions. There are many other kinds of machinery which require mechanical means of changing speeds. The variable speed mechanisms in general use vary greatly in design. The sections VARIABLE SPEED MECHANISMS, Vol. VI, p. 418, and SPEED AND FEED MECHANISMS, Vol. V, p. 402, include a variety of types and designs which have been developed to meet different conditions. Most of the designs illustrated are intended for a certain type of machine or mechanism, and sometimes could not be applied to another type without more or less modification. A study of these different mechanisms, however, will prove invaluable to the designer or student interested in various classes of mechanical apparatus, because they embody fundamental principles which may be applied generally to machines of different kinds, provided the details of construction are modified in accordance with the conditions in each case.

PRINCIPLES OF MACHINE DESIGN

IN the building of machines, there are two fundamental and distinct processes—(1) the imagining or conception of the design in the mind and the recording of this design on a drawing, and (2) the actual building of the machine from the drawing, which involves shaping the parts by various methods from iron, steel, or other materials. In the early development of the art of machine building, many machines were constructed without an adequate design. The builder would carry a general idea of the machine he wanted to build in his mind, and would himself, together with his assistants, gradually complete the machine one part at a time, to fit properly into the parts already made. This was a primitive and expensive method of developing machines and often resulted in crude and unsatisfactory forms, as changes were difficult to make and it was not possible from the beginning to gain a clear conception of the relationship of the different parts. As the art of machine building developed, the making of a drawing of a machine, before an attempt was made to build it, became common practice, and, today, the advantages of this method are so generally recognized that there are very few instances in which the design is not first completed in all its details on drawings, before any attempt whatever to make the machine in solid materials is made. This practice, in turn, has led to the development of what might be termed a specific trade — that of the mechanical *draftsman* and machine *designer*.

The Work of Draftsmen and Designers. — While the two terms "draftsman" and "designer" are often used interchangeably, a designer is a man who conceives in his mind the arrangement of the parts of a machine or device for accomplishing a specific purpose, and who is able to proportion this machine or device properly as regards strength, functions, and appearance, so that it meets the requirements. A designer is also always a draftsman, able to put his ideas on paper in the form of a drawing; but a draftsman may not always be a designer. He may merely be able to work out the details from a complete design already made, and to produce working drawings for the shop, from which the parts can be made according to the ideas embodied in the drawing made by the designer; but no distinct line can be drawn between the work of a draftsman and the work of a designer, as every draftsman, to be of any value, must, in some measure at least, be a designer. If he is only able to copy the drawings or the designs of others, he would hardly be called a draftsman, but would be classified as a "tracer."

A machine designer, to be proficient in his calling, must possess knowledge covering four distinct phases of mechanical work. He must understand the principles of mechanical drawing so that he can record his ideas correctly on paper; he must be versed in the strength of materials, which virtually amounts to a science, so that he is able to properly proportion the parts of the machines he designs to resist the stresses placed upon them; he must understand the laws of mechanics and kinematics so that he can properly arrange the parts of the machine to be designed, so that they will perform their proper functions; and finally, he must know enough about the methods and practices used in the shop in the building of machines, so that he can design the machine in a manner making it possible to build it in the cheapest and most efficient manner.

Drawing and Drafting-room Systems. — Mechanical drawings may be considered as the written language of the shop. On the drawing, the designer and draftsman write down their ideas in a language which the shop man reads preparatory to making the machine parts required. Just the same as there are good and poor handwritings, and just as some have a greater ability to express their ideas in words than have others, so the proficient draftsman has a greater facility for clearly showing his ideas on a drawing than has a less proficient man. It takes long experience and good judgment always to know exactly how a drawing should be made in order to indicate most clearly how the object shown is to be constructed. This is especially true of complicated castings where it sometimes takes considerable ingenuity on the part of the draftsman to make a drawing in such a manner that its intent will be perfectly clear to the patternmaker who makes the pattern for the casting. The patternmaker, as a rule, requires greater ability in the reading of drawings than does the machinist, because, when a complicated casting reaches the machining stage, the machinist has both the drawing and the casting, and it is easier for him to see what has to be done than for the patternmaker who has nothing but the drawing to work from.

It has not been attempted in the ENCYCLOPEDIA to teach how to make drawings, because this subject is of such a nature that anyone studying it would require special text-books intended for that purpose alone; but the ENCYCLOPEDIA contains articles relating to the principles of making drawings which will be of value to both shop men and draftsmen. The article on DRAWINGS FOR SHOP USE, Vol. II, p. 422, is, therefore, not intended to teach a draftsman everything that he would need to know about the making of drawings, but to present to him a review of the principles involved, and also to teach the shop man the meaning of certain representations, lines, and methods used on drawings. Anyone who wishes to obtain a comprehensive idea of the principles of the subject should read this section. There are two other sections on drawing that have been especially prepared for the draftsman and designer, because they cover subjects on which the mechanical draftsman, as a rule, is not well versed, but which at times prove of considerable value to him. These sections are Isometric Projection, Vol. IV, p. 86, and Perspective Drawing, Vol. V, p. 8. By means of both isometric projection and perspective drawing, it is possible to represent an object approximately as it would appear to the eye, by using one view only, whereas ordinary mechanical drawing uses a number of views and does not represent the object in any one of these views in the form in which it would appear to an actual observer. When machines or machine parts are to be drawn for presentation to persons not familiar with mechanical drawing, isometric or perspective drawings are of great value.

Apart from the work of designing and drawing machine details, the draftsman is also, as a rule, required to maintain records relating to the machines that have been designed, and drawings pertaining to them. Sometimes the drafting-room maintains also records covering certain features of the production departments. In order to do this work efficiently, drafting-room systems must be devised, so that the records may be kept in a systematic and orderly manner. There are a great number of different drafting-room systems — perhaps as many as there are drafting-rooms; but there are certain fundamental principles that may be laid down and which can be profitably followed in the majority of cases. In the article on Drafting-room Systems, Vol. II, p. 398, some of these fundamental principles are dealt with.

Draftsmen's Tools, Drawing Paper, and Materials. — A draftsman, in his work, employs tools that are as distinct and specially designed for their purpose as are the tools used by the machinist or toolmaker in his work. These tools are designed with a view of neat and accurate representation of the objects to be drawn; hence they provide means primarily for drawing straight lines and circles, for drawing lines at right angles to each other, and for drawing lines at any predetermined angle. The tools required by the draftsman are described in the article Draftsmen's Tools, Vol. II, p. 401. This article can be used as a guide by anyone studying mechanical drawing and equipping himself with the required tools, as it advises not only the kinds of tools that are required, but also the types most useful for ordinary work.

Drawings are made on special kinds of paper produced for drafting purposes only. These papers are usually much heavier than ordinary paper and of a coarser finish. There are many different kinds of drawing papers varying in price and quality and intended for different classes of drawings. The draftsman who has anything to do with the selection of drawing paper will, therefore, find in the article on Drawing Paper, Vol. II, p. 420, such information relating to the different kinds as will be useful to him. When diagrams for facilitating calculations to be made in the drafting-room or for recording tests are frequently made, Logarithmic Paper, Vol. IV, p. 239, will be found convenient.

Tracings and Blueprinting. — In most shops, a paper drawing is not sent directly into the factory, because, if this were done, it would soon become soiled and torn, and would be unfit for further use. Tracings — that is, drawings made on specially prepared transparent cloth or paper — are, therefore, made from the drawings, and from these tracings, blueprints or copies made in a manner similar to photographic copies, by the action of light, are then produced. These blueprints are sent into the shops. It is evident that this is a great convenience, because as many blueprints as are required can be made from time to time from the tracings, and yet the original drawing and tracing remain in a good condition. The methods of making tracings are briefly described in the article on Tracings, Vol. VI, p. 301, and blueprints and blueprinting are dealt with in the article on Blueprinting, Vol. I, p. 392.

The Art of Machine Design. — The knowledge of how to make drawings is, however, a comparatively small part of that necessary for a designer in his work. The art of a machine designer is one which it is difficult to define. He is, to a certain extent, an inventor, but he is also largely an adapter of former inventions to his present design, and generally his abilities as an adapter are far more valuable than his abilities as an inventor. Practically, machine design does not consist so much in inventing radically new devices as in adapting old and well-known mechanisms and principles to new uses, and arranging them in different relations to each other, so as to perform new functions. Sometimes work of this kind may be classed as invention, but, as a rule, it is not. Invention is the devising of an entirely new mechanism or an application of mechanical principles in a radically new manner. Inventions are new departures, while machine designing generally consists of adapting well-known principles to new arrangements and functions. This distinction between designing and inventing by no means lessens the importance of the work of the machine designer. It is often as difficult, and certainly as important, to be able to apply known and tried devices and methods to perform new operations as it is to devise something entirely new. As an example, in the construction of a machine requiring a friction clutch, the experienced designer would endeavor to so arrange his machine that he could employ a clutch of standard make, rather than to attempt to invent one himself. The adaptation of machines to the use of standard parts, whenever they can be used, is the most economical method of building machines. The machine designer who insists upon making original designs of his own for all mechanisms required in his machines is a less efficient man than one who confines his work to the arrangement and modification of devices already known to give satisfactory service and thoroughly tried out in practice. The best qualification of a machine designer, therefore, is not his ability to invent, but his ability to make proper use of existing inventions. When with this ability is coupled a fair degree of inventive ability, he becomes a highly efficient man in his trade.

Machine Design and Strength of Materials. — In the same way as arithmetic contains the basic principles of all other mathematical study, so a knowledge and understanding of the strength of materials is a basic requirement in the art of machine design. Without this knowledge, it would be impossible to proportion machine parts to properly perform their functions, except by previous experience with parts of certain proportions that have proved strong enough; but when new machines of different proportions would have to be built, there would be no certainty that the parts would be strong enough for their work, and if they were made of such large proportions that they would be certain to be amply strong enough, there might be a great deal of waste of material, which would bring up the cost of the machine in an unnecessary degree. In the case of structures such as bridges, it becomes absolutely necessary to have means for calculating the strength, because an improperly proportioned bridge might even fail under its own weight, not to mention the weight of the load that might be placed upon it when in use. To the successful machine designer, therefore, one of the most important subjects of study is that which will enable him to determine the stresses to which a machine member is subjected, in order that it may be given adequate strength for the purpose intended.

There are many instances when it is not necessary to calculate the strength of a part in the design of a machine, while in other instances it is highly desirable, or necessary, that this should be done. Whenever calculations can be conveniently made, they should be carried out; but successful designs and the results of practical experience should be compared with the calculated results wherever possible, as in this way theory and practice can be made to supplement each other. There are many practical conditions, especially when such metals as cast iron are dealt with, that require consideration in addition to mere calculated strength, and in all cases when machine parts are exposed to excessive wear, this factor must be considered also. Sometimes wear is more important than strength. This applies often in the design of gear teeth. It should, therefore, be understood that, while the subject of the strength of materials is highly important and one which the machine designer cannot afford to ignore, there are no hard and fast rules to follow for many problems relating to the strength of materials, but judgment and experience will always prove valuable aids to the designer.

Strength of Materials and Theory of Stresses. — In the section STRENGTH OF MATERIALS, Vol. VI, p. 95, the principal methods used in calculating the strength of parts used in machine design and engineering work are given in as simple a manner as possible. While the formulas used are given in such a shape that they can be directly employed by the practical man, it should be understood that it is not possible to study this subject unless the student is familiar with the use of FORMULAS, Vol. III, p. 201; and some of the more advanced parts of the subject require an understanding of the principles of ALGEBRA, Vol. I, p. 60, and EQUATIONS, Vol. III, p. 67.

The science of strength of materials comprises not only a knowledge of the actual strength of different metals and materials in tension, compression, or torsion, but also the methods by means of which the strength of machine parts shaped in different ways may be determined. In many instances, it is not possible, however, to give a formula that can be directly applied. The subject is not as simple as that, but requires considerable study in order to enable the user to properly employ the various methods and formulas. When a part is subjected to a straight pull or tension, or a direct pressure or compression, the problem is very simple, but when subjected to bending, as in the case of beams, the subject is more difficult. (Any part of a machine and structure supported or held at one or more points and having a load applied at a point which is not directly supported, is mechanically known as a "beam.") It is not possible to state the strength of a material in bending in the same way as we can say that it has a strength of 60,000 pounds per square inch in tension or compression. The methods that the machine designer must employ in calculating his safe load for a part subjected to bending, however, are explained in the general article on STRENGTH OF MATERIALS, under the headings *Bending Stresses* and *Bending Moments*, Vol. VI, pp. 103 and 104. A complete collection of formulas required in beam calculations is given in the article on BEAMS, Vol. I, p. 264. In practice, beams are generally made from structural steel shapes. These steel shapes have been standardized by the steel companies, and, in designing a beam, tables giving the dimensions and properties of these standard shapes are of great value. Information relating to them is given in the ENCYCLOPEDIA under the headings STRUCTURAL STEEL (Vol. VI, p. 111); ANGLES, STRUCTURAL (Vol. I, p. 95); CHANNELS, STRUCTURAL (Vol. II, p. 81); I-BEAMS (Vol. IV, p. 45); and Z-BARS (Vol. VI, p. 563). In these articles, the dimensions are tabulated, together with such data as will make the calculation of the strength of these structural sections more convenient.

Crane and Crane Girder Design. — As a specific example of beam design and its important relation to machine design, the design of crane girders may be mentioned. It is, of course, of the greatest importance that crane girders be made strong enough for the maximum load that the crane is intended to lift. It is also important that the amount of material used in the girder does not exceed that which is necessary for its strength, as an excessive amount of material would increase the cost without increasing the usefulness of the crane. There are many different types of crane girders in use, and the application of the principles of the strength of materials and the loads and stresses applicable to beams are well exemplified in their design. Crane girders for overhead traveling cranes are, therefore, dealt with in a complete article in the ENCYCLOPEDIA under the heading CRANE GIRDERS, Vol. II, p. 257. The subject of crane design, in general, offers one of the best practical applications of the theory of the strength of materials, and is dealt with in the section on CRANE DESIGN, Vol. II, p. 232. Another important application to machine design is found in the article PUNCH AND SHEAR FRAME DESIGN, Vol. V, p. 213.

Compound Stresses. — While most of the laws and principles relating to the strength of materials have been well known for many years, there are constantly new fields being investigated that have not been thoroughly explored in the past. Among these is the subject of compound stresses, that is, the effect on a machine part that is simultaneously subjected to pulls or pressure in a number of different directions. This subject belongs to a more advanced stage in the theory of machine design, and has only recently been fully understood. The present stage of the knowledge on this subject is explained in Vol. VI, p. 107.

Factor of Safety. — In machine design, it is not sufficient to provide a part that is just strong enough for the stress that would be placed upon it; it must be sufficiently stronger, so that it will not break after continued use, or if subjected to shocks or unusual accidental stresses. To provide for such contingencies, a factor of safety is introduced into the design. This factor of safety differs according to the uses of the machine part. It is less for a steady load than for loads that increase and decrease in amount, and it must be much greater for parts subjected to shock than for any other condition. It must also be greater for brittle materials than for those of a more tenacious structure. It is one of the important considerations in machine design, and a thorough understanding of the factor of safety is of importance in the successful use of any of the formulas or principles involved in the calculation of the strength of machine parts. The subject is completely dealt with in the article FACTOR OF SAFETY, Vol. III, p. 92.

Flat Plates, Cylinders, and Columns. — There are a number of conditions in machine design which are not susceptible to an accurate mathematical treatment and for which formulas based upon experience have been developed — so-called " empirical " formulas, which are not developed by theoretically accurate means. Among these, the most important are the formulas that have been developed for the design of cylinders subjected to internal pressure, for the design of flat plates supported at their edges and subjected to pressure inside of the supporting area, and for columns or struts. The strength of cylinders subjected to internal pressure has been very thoroughly investigated, and very careful tests have been made so that the formulas developed for the calculation of steam and hydraulic cylinders may be considered quite accurate for practical purposes. This subject is dealt with under CYLINDERS, STRENGTH OF, Vol. II, p. 299. In the case of flat plates subjected to pressure, as, for example, cylinder heads, the condition is not so satisfactory, as the numerous formulas produced for this work do not agree very closely, and the tests that have been made have not led to the development of universally accepted methods of calculation. The various formulas that have been developed from time to time by investigators of the strength of flat plates are given, however, in the article on FLAT PLATES, Vol. III, p. 154. In the case of columns or struts, the great importance of this subject in structural work has led to very thorough investigations and very satisfactory formulas have been developed. These are given in the article COLUMNS OR STRUTS, Vol. II, p. 168.

The Testing of Engineering Materials. — The strength of a material in itself, such as steel, brass, copper, etc., cannot be calculated, but must be determined experimentally before calculations can be made on the strength of parts made from that material. These experiments, however, need not be made by the machine designer, because such experiments have been carried out in the past with practically every known engineering material, and are recorded in tables in all engineering handbooks, as well as in the ENCYCLOPEDIA. The strength per square inch varies, of course, with the quality of the material, but, within certain limits, the experimental values that have been developed may be considered as accurate for any ordinary material, and as the factor of safety must be assumed great enough to allow for any reasonable variations, the figures given in tables of ultimate strength for any of the well-known materials may be used as a working basis for all calculations of this kind. When new or unusual materials are used, however, the designer should not make important parts from these materials without having ascertained their strength, and thus made sure that they will be found suitable for the purpose for which he intends them.

The strength is ascertained by means of testing machines which are made to test materials in tension, compression, and torsion, as well as for shearing strength and impact. When the hardness of a material is of importance, hardness tests are made by a number of different methods. The principles involved in the making of tension, compression, shearing, torsional and other tests are explained in the articles TESTING MATERIALS (Vol. VI, p. 224); HARDNESS TESTING (Vol. III, p. 527); and IMPACT TESTS (Vol. IV, p. 46). In order to make these tests comparable with other tests, certain dimensions of test-bars have been adopted, and the exact tests to which these test-bars must be subjected have been prescribed. The American Society for Testing Materials as well as the International Society for Testing Materials have done a great deal of work in this direction. Cast iron is especially an uncertain material, and tests are frequently made on test-bars from each cast. (See ARBITRATION BAR, Vol. I, p. 109.)

STANDARD AND SPECIAL MACHINE DETAILS

MANY of the complicated machines now used for performing, automatically, different manufacturing operations are very impressive when seen at work, because of the rapidity with which the raw material is shaped into the finished product. If a machine of this kind were taken apart and each detail examined in order to discover what the wonderful features are, the miscellaneous collection of bolts, keys, pins, shafts, pulleys, gears, levers, and slides, when viewed separately, would not be so impressive, but they would illustrate an important fact regarding the design or construction of any machine; namely, that it is a step-by-step process; and a knowledge of the subject must be acquired in the same way. Many machines, when assembled, seem hopelessly complex, and one might naturally wonder how such an intricate mechanism could be devised or built. The experienced designer knows that work of this kind requires an intimate knowledge of machine details and of the practicable methods of combining the details to secure different results. The old adage that a "chain is no stronger than its weakest link" also applies, in principle, to some machines, which are not better than the least satisfactory detail.

Method of Studying Machine Design. — After the fundamental principles of machine design are understood, the student should study the various details which are used to form different classes of mechanisms, beginning with those adapted to general use and continuing with more special mechanical features. It is advisable to supplement this branch of study by reading descriptions of all kinds of mechanisms and machines, in order to obtain a general knowledge of the methods of combining various details for transmitting motion, for controlling motion, for obtaining changes of speeds, and to secure many other results and effects essential in the operation of different classes and forms of mechanisms. Some of the more important articles pertaining to machine details are referred to in the following pages, and throughout the ENCYCLOPEDIA will be found various classes of mechanisms which show different ways in which these details may be applied.

Bolts, Nuts, and Screws. — Most machine parts are held together by bolts or screws, which are usually made in accordance with generally recognized standards. The article on BOLTS AND NUTS, Vol. I, p. 453, includes tables for United States and Whitworth standard threads, bolts, and nuts. That part of the article on the working strength of bolts is of especial importance to students of machine design. When machines are subjected to constant vibration and jarring, the nuts on bolts tend to work loose unless special provision is made for holding them in place; in fact, the loosening of nuts and bolts due to constant vibration has been the cause of much trouble and damage. The result is that a great many nut-locking devices have been devised. Many of the more important types are illustrated and described in the article on LOCK-NUTS, Vol. IV, p. 222. General information on different forms of screws and bolts will be found in Vol. V, p. 324, which deals with various classes of machine screws, cap-screws, studs, set-screws, bolts, and wood-screws.

Keys, Cotters, and Pins. — Keys represent another common form of fastening device, and are used on practically all classes of machinery to hold parts in fixed positions relative to each other. Keys are indispensable as a means of preventing relative rotation between shafts and pulleys, gears, etc. The various methods of applying different types of keys are explained in the article on KEYS AND COTTERS, Vol. IV, p. 144. This article is also accompanied by considerable data on the proportions of different types of keys, and includes general rules for determining key sizes, information on key fitting, the measuring and gaging of keyways, the effect of keyways on the strength of shafts, methods of applying cotters, and cotter-pins.

In the construction of some kinds of machinery, taper pins are used to hold parts in a fixed position or to prevent relative movement. The article on TAPER PINS, Vol. VI, p. 180, includes the standard dimensions of various sizes adopted by the principal manufacturers of such pins.

Machine Handles and Handwheels. — In the operation of many classes of machinery, and especially those included under the general heading of "machine tools," hand adjustment of tool-slides, carriages, etc., are often necessary. The general efficiency of a machine may be considerably affected by the design of the handles, levers, or handwheels with which it has been equipped, especially if the machine is manipulated frequently, or entirely, by hand. In connection with the article on HANDLES, Vol. III, p. 503, a number of the more commonly used handles of the crank and plain lever types are illustrated, and their special application noted. The article on HANDWHEELS, Vol. III, p. 510, also includes some important information on this subject.

Shafts. — There are comparatively few types or designs of machines which do not have one or more shafts as a means of transmitting motion, either directly or through gears, pulleys and belts, or sprockets and chains. The use of shafting in a design involves a consideration of the stresses to be imposed on the shaft and the means of supporting and holding it in position. The principal stresses to which shafts are ordinarily subjected are usually torsional or twisting stresses, but, in some cases, it is necessary to consider the bending stresses, or the combined torsional and bending stresses, as, for example, when a shaft supports a very heavy pulley. Reference should be made to the section on SHAFTING, Vol. V, p. 331, for the general formulas for torsional strength and for the procedure when there are bending stresses, or combined torsional and bending stresses, of sufficient magnitude to require consideration. Shafts are often used for transmitting motion from some part which must be free to move either for occasional adjustment or to permit a feeding movement for a cutting tool or grinding wheel. If the motion were always in line with the axis of the shaft, some form of telescopic connection could be employed, but movements in other directions require either flexible shafting (see Vol. III, p. 156) or some form of universal joint (see Vol. VI, p. 375).

The methods of supporting shafts vary considerably. The lineshafting used in many machine shops and factories for the distribution of power revolves in bearings carried by shaft hangers, which may either be attached to overhead floor beams or to rows of vertical posts or columns (see HANGERS, Vol. III, p. 512). The bearings for very heavy shafting and for the various kinds of shafts used in different classes of machines vary greatly, the design depending upon such factors as the load, the speed, the location of the bearing relative to injurious substances, the necessity of providing for endwise thrust, and other important points that must be considered in connection with bearing construction and design.

Couplings and Clutches. — When a long, continuous line of shafting is required for distributing or transmitting power to many different machines in a shop or factory, such a shaft is built up of sections, the ends of which are joined together by couplings. These couplings are so designed that the shaft ends are rigidly held together, and the entire line of shafting rotates as a unit. Some couplings, instead of forming rigid connections, are so designed that one shaft section is permitted a slight movement relative to the adjoining section. This flexibility in the connection may be desirable to compensate for slight changes in alignment or to provide enough flexibility in the drive to reduce the shock when starting the driven member. Various classes of rigid and flexible couplings are described in the section on COUPLINGS, Vol. II, p. 228.

When a coupling is so designed that two shafts may be connected or disconnected at will, it is classified as a "clutch." Clutches of various kinds are used extensively as a means of controlling motion, in connection with the starting or stopping of machines, etc. The section on CLUTCHES, Vol. II, p. 132, deals with different types of positive clutches, or those having teeth which interlock; various kinds of friction clutches, or those which transmit motion by the frictional resistance between engaging surfaces; clutches which are tripped or disengaged automatically; automobile transmission clutches; magnetic clutches, etc. This section includes information of value to the man in the shop as well as the designer of machinery.

Bearings for Revolving Parts. — There are few subjects related to the design or construction of machinery which are of greater importance than the subject of bearings, especially if high speeds are necessary or the bearings must withstand heavy radial or endwise loads. An unsatisfactory bearing may stop a machine, cause a shop or factory to shut down temporarily, or tie up a railroad. The trouble may be the result of faulty design, inaccurate construction, lack of lubrication, or inadequate protection from gritty material. The design of bearings, in general, may be affected by the class of machine or mechanism on which the bearings are required; the nature of the load; the speed; the importance of reducing friction to a minimum; the means of lubrication; the necessity of protecting the bearing from foreign matter which might enter it and injure the bearing surfaces; the kinds of metal for the bearing surfaces; and the relation between the general requirements and cost of the machine as a whole, and the type of bearing that is practicable. The section on BEARINGS, Vol. I, p. 305, should be read first, as it is in the nature of a general treatise covering types of bearings for radial and endwise loads; frictional resistance; the generation of heat in bearings; the effects of proper lubrication; and how bearings are proportioned relative to the load and speed.

The flat bearing surfaces of machine slides vary so widely in form and size, and are so dependent upon the design and particular requirements of each type of machine, that they are not dealt with in a separate article. One of the essential features of slide bearings, in general, is the means of eliminating lost motion. Any appreciable amount of play is particularly objectionable in the slides used on different classes of machine tools, especially when the accuracy of the work is dependent upon the movements of slides. The general method of compensating for wear is by means of wedge-shaped strips called "gibs." These gibs are applied in various ways and differ considerably in form and in the method of adjustment. (See GIBS, Vol. III, p. 412.)

Ball and Roller Bearings. — Friction is one of the greatest causes of waste in the mechanical field, as it wears out machinery and wastes energy without accomplishing useful work. Mechanical friction is always a resisting force, and sometimes the designer of machinery provides means of increasing it, as, for example, when the transmission of motion or power is dependent upon the frictional resistance between two surfaces in contact, as in the case of friction gearing, friction clutches, or a belt operating on pulleys. In most cases, however, one of the important problems in machine design is to eliminate friction as far as possible, in order to increase the efficiency of the machine and conserve energy for useful work. The man who first applied wheels to a road vehicle discovered that much less effort was required to roll a load along than to slide or drag it. Ball and roller bearings are based on that principle. These bearings are now applied to so many different classes of machinery that a general knowledge covering their design and the methods of utilizing different types is essential to everyone interested in the subject of machine design. In the application of such bearings to a machine, it is also essential to mount them correctly and in accordance with the characteristics of different types of bearings. The section on BALL BEARINGS, Vol. I, p. 209, covers the various points pertaining to the design and application of bearings of this class, including both radial and thrust bearings; methods of mounting them; their application to different classes of machinery; and suitable lubricants for ball bearings. In connection with this general treatise, the article on BALL MANUFACTURE, Vol. I, p. 225, and also the article on BALL RACE GRINDING, Vol. I, p. 241, will be found instructive, since they deal with unusual manufacturing operations that require special processes and machines.

Roller bearings operate on the same general principle as ball bearings, but cylindrical or conical rollers are used instead of spherical balls. Bearings of this type are designed either for radial loads, for combined radial and endwise or axial loads, or for withstanding endwise thrust exclusively. A general treatise on roller bearings will be found in Vol. V, p. 274.

Bearing Lubrication and Protection. — Bearings may be carefully designed with reference to the loads they will have to support, and in such a way that any necessary adjustment can readily be made, but if the means of lubricating the bearing surfaces have been neglected or slighted, the effects of this neglect will generally be discovered first after the machine has been constructed and is in use. The skilled designer anticipates trouble and prevents it, but such ability and foresight must be developed by a study of the principles and facts demonstrated by experience and practical tests. While the subject of lubrication has always been an important one, it requires more attention at present than ever before, because of the higher speeds and more severe conditions of service which now prevail in the operation of many classes of machinery. In providing a lubricating method, it is essential to consider the provision of an unfailing supply and a reliable system of distributing the lubricant to the bearing surfaces. In the section on BEARING LUBRICATING METHODS, Vol. I, p. 280, will be found information on various methods of supplying and distributing lubricants to different types of bearings. A great many bearings will be subjected to the abrading action of gritty material unless they are properly protected. This is especially true of machinery used in manufacturing processes which produce a considerable amount of dust. In the operation of grinding machines or metal-cutting tools, the dust from the grinding wheels or the fine chips from the tools often cause bearing troubles when the bearing surfaces are not protected. (See BEARING PROTECTING DEVICES, Vol. I, p. 300.)

Pulleys and Flywheels. — The pulleys used in shops and factories and on different kinds of machinery for transmitting motion or power by belting may be made either of cast iron, wood, or steel, and they may also vary in regard to the shape of the rim, the number and arrangement of the arms or spokes, and other details of construction (see PULLEYS, Vol. V, p. 180). Cone-pulleys represent a special class which has been used extensively on many types of belt-driven machine tools for obtaining speed variations. Cone-pulleys are usually made so that there are equal differences between the diameters of the steps or sections forming the pulley. This simple method of designing a pulley, however, will not always give satisfactory results, as explained in the article on CONE-PULLEY DESIGN, Vol. II, p. 184. The object is to so proportion the different steps of the driving and driven pulleys that a belt of fixed length will have practically the same tension for any position on the pulleys.

A great many machines would not operate properly without a flywheel or balance wheel. The purpose of a flywheel is to cause steadiness of action by preventing sudden changes of velocity, by storing up energy which can be utilized either when the source of power diminishes or the resistance to motion increases. Flywheels are used on such a variety of mechanisms that they are made in all sizes ranging from a few inches in diameter to 15 or 20 feet or more. The care with which the flywheel must be designed and constructed depends largely upon the speed at which it must rotate, or the rim velocity. The section on FLYWHEELS, Vol. III, p. 160, contains general information on different types or designs of flywheels, the materials used in their construction, the safe speeds at which they may be operated, and includes formulas applicable to the design of flywheels for steam engines, gas engines, and punching and shearing machinery.

Design of Gearing. — Problems relating to the design of various classes of gearing are probably encountered more often than any others, both by draftsmen and machine designers and by men in the shop. The design of gearing, in general, usually depends upon such factors as the relative positions of the driving and driven gear as required by the location of the gear shafts in the machine, and also upon the relative speeds of the driving and driven gears, as well as upon the amount of power to be transmitted. If the shafts are parallel, spur gears would ordinarily be used. If the shafts are at an angle, but in the same plane, or only slightly offset, bevel gears would probably be used, whereas, if they are at an angle, but quite widely separated, spiral gearing or worm gearing might be employed.

Every machine designer should understand thoroughly the principles of gear design, the particular advantages of different types of gearing and the conditions governing their use, how gears may be applied in various combinations either for obtaining speed changes or for securing a decided increase in the effective power transmitted, or a great reduction or increase of speed, what materials are adapted to gear construction, and the general methods of producing gears on a commercial basis. The subject of gearing is covered completely in the ENCYCLOPEDIA, because it is important to almost every one engaged in mechanical work. The following articles include the principal sources of information and constitute a complete treatise on both the theory and practice of gearing: SPUR GEARING, Vol. V, p. 501; STUB-TOOTH GEARS, VOL. VI, p. 111; INTERNAL GEARS, Vol. IV, p. 75; BEVEL GEARING, Vol. I, p. 352; SPIRAL TYPE BEVEL GEARS, Vol. V, p. 470; SKEW BEVEL GEARS, Vol. V, p. 367; WORM GEARING, Vol. VI, p. 541; HINDLEY GEARING, Vol. IV, p. 7; SPIRAL GEARING, Vol. V, p. 461; HERRINGBONE GEARS, Vol. III, p. 544; INTERMITTENT GEARING, Vol. IV, p. 72; RATCHET GEARING, Vol. V, p. 232; EPICYCLIC GEARING, Vol. III, p. 64; ECCENTRIC GEARS, Vol. II, p. 518; and ELLIPTIC GEARS, Vol. III, p. 50. These articles are intended primarily for the designer of gearing, although they contain much practical information of use to the machinist or shop foreman. The different types of machines used for gear cutting and the methods of using them are referred to in separate articles in Vol. III, pp. 322 and 331.

Design of Cams. — Whenever a machine part requires a complex or irregular movement, the motion is usually derived from some form of cam; in fact, the most complicated forms of mechanisms, especially of the classes that perform a series of operations automatically, receive their intricate movements from cams of different forms. After the principle of cam design is understood, it is comparatively easy to obtain almost any motion likely to be required. The section on CAM DESIGN, Vol. I, p. 530, describes how to lay out both disk or plate cams and cylinder cams, for obtaining different mechanical movements. One of the most interesting applications of cams is found on automatic screw machines. The article CAM DESIGN FOR SCREW MACHINES, Vol. I, p. 542, explains how a set of cams would be laid out for a given operation on a Brown & Sharpe machine, and includes general information on this subject which will prove helpful in the design of cams generally.

Design and Use of Springs. — Springs, as applied to the design of machinery in general, may be used either to absorb shocks, to hold parts in a given position, but provide sufficient flexibility to permit movement, or to impart motion to a plunger, lever, or slide, at a predetermined point in a cycle of movements, by tripping or releasing a compressed spring. The springs of automobiles, railway cars, and locomotives are examples of their application primarily as shock absorbers, and illustrations of the other uses referred to will be found in numerous designs of tools and machines described throughout the ENCYCLOPEDIA. The inventor or experienced designer appreciates the value of springs as a simple and inexpensive means of controlling the action of some movable part, notwithstanding the fact that springs are often considered objectionable and may be a source of trouble, particularly if substituted for more reliable forms of construction. If springs are used with judgment, however, and are properly applied, they will often prove the only practicable means of accomplishing a desired result. Springs of various forms are found on machines of the best quality and workmanship. The section on SPRINGS, Vol. V, p. 492, is a complete treatise on the subject and covers different types of springs, the materials used in their construction, formulas for determining safe loads, and the amount of deflection when subjected to a given load. (See also SPRING COILING, Vol. V, p. 480.)

Locking Devices for Machine Tools. — Many of the machine tool slides and spindles of the class which are adjustable, but not necessarily in motion when the machine is in use, are provided with some means of holding them rigidly in position. The function of the clamping or locking device may be simply to eliminate vibration, or the object may be to hold a slide, turret, or gear in a definite position relative to other parts of the machine. Many different designs and types of locking devices are shown in connection with the article CLAMPING OR LOCKING DEVICES FOR MACHINE TOOLS, Vol. II, p. 123. Appliances of a somewhat different class are described in the article on CENTERING MECHANISMS, Vol. II, p. 40.

Stopping and Reversing Mechanisms. — Many types of machine tools, as well as other classes of mechanisms, require some form of mechanical device either for limiting the movement of a machine part or to cause a reversal in the direction of motion. In the case of machine tools, it is often necessary to control the motion of a tool-slide in this way, either to insure stopping the cutting action of a tool at a definite point, or for some other reason. The feeding mechanisms of many machines are arranged for automatic disengagement at any predetermined point, and there are numerous other examples or applications of stop and tripping devices. A reversal of motion is also essential to the operation of many machines. The reversing mechanism may be so arranged that the reversal of motion occurs at a fixed point in the cycle of movements, or the construction may be such that the time of reversal can be varied at will by adjusting or changing the positions of dogs or tappets, which are attached to the movable part and control the action of the reversing mechanism. Various designs of mechanical devices of the classes referred to are described in the article STOPS, TRIPS, AND REVERSING MECHANISMS, Vol. VI, p. 84.

Brakes and Brake Design. — Brakes are not applied as generally in machine construction as most of the other details previously referred to, their principal application being to railway cars, locomotives, automobiles, and to the different classes of hoisting machinery. The energy of the moving or revolving part, to which a brake is applied, is absorbed by the frictional resistance of the braking surfaces. The brake may be intended, primarily, to arrest the motion quickly, or to control it and prevent excessive speed, as when a heavy load is being lowered by some form of hoisting apparatus. In the design of brakes, it is essential to consider the means of applying the braking pressure, the frictional resistance of the braking surfaces, and the dissipation of the heat generated when the brake is applied, the latter feature being of particular importance if long applications of the brake are necessary. (See BRAKES, Vol. I, p. 479.)

IRON AND STEEL

IRON and steel are so closely interwoven with every phase of modern life that it is impossible to appreciate their full importance and value. Almost everything that we use or see about us is related in some way to iron or steel. These materials are connected with every sphere of human activity, and the progress of the world has been dependent upon them. Practically all manufactured articles, if not made wholly or partly of iron or steel, are products of a machine constructed principally of iron and steel; in fact, the machine is back of nearly everything which goes to make up present-day civilization. Every means of transportation, every implement or apparatus, every building and its contents, and the innumerable things which enter into our economic life, represent, in various degrees, the work of machines which are usually made almost entirely of iron or steel. Even the page on which these words are printed is a machine-made product, and one can scarcely look in any direction without seeing something that the human brain has created by means of some form of mechanical apparatus.

Abundance of Iron Ore Deposits. — Every man interested in the subject of mechanics and engineering should possess at least a general knowledge of the processes by which the crude iron ore found in the earth is transformed into iron and steel parts, differing widely in their physical properties and industrial applications. With the exception of aluminum, the deposits of iron are larger than those of any other metal. The use of iron antedates the beginning of authentic history. It is generally supposed that copper and bronze were used before iron, notwithstanding the fact that the process of extracting copper and alloying it with tin to form bronze required greater metallurgical skill than the smelting of iron ore. Some authorities, however, contend that the use of iron antedates that of copper or bronze simply because it is more easily obtained from the crude ore. While there is no definite information on this point, it is interesting to know that in the records of the Egyptians reference is made to the manufacture of iron, which was doubtless done on a very small scale. Some of the ancient sources of iron ore supply were India, the island of Elba, the south coast of the Black Sea, Algeria, and Spain. Iron ore for the industries of both Greece and Rome were obtained from Elba and from other deposits; some of these ancient sources of supply have been of considerable importance in modern times. More iron ore is now obtained from the deposits in the United States than from any other country, most of this ore coming from the Lake Superior district.

In the production of iron and steel, it is necessary to consider the kinds of ore that are obtained from different mines and districts, how they are smelted and refined to produce iron or steel of various grades, and how the iron and steel are worked up into bars, rails, sheets, and other forms required by various metal-working industries.

Iron Ore. — Iron ore, as it is extracted from the mines, varies considerably in value and commercial importance, owing to differences in the percentage of iron and other elements. While the amount of iron in the ore is the first consideration in determining its value, the other elements are also of considerable importance. Information regarding iron ore and its various commercial grades will be found in Vol. IV, p. 84. This section on iron ore deals with the composition and characteristics of different grades, the elements other than iron and their effect on the industrial value of the ore, and the different processes for improving ores before smelting.

Blast Furnaces. — The smelting of iron ore, or extracting the iron from the other elements forming the ore, is done in what is known as a "blast furnace." The primitive method of producing iron was by applying a blast to a mixture of wood or charcoal and ore, by digging a hole into the side of a bank or hill exposed to the prevailing winds so as to obtain a natural draft. Later, a blast of air was obtained artificially, probably by means of a bellows. From this crude beginning, the melting of iron passed through a varied evolutionary process which finally led to the modern blast furnace with its hot blast stoves and blowing engines for supplying large volumes of heated air, mechanical conveyors for handling the fuel, ore and bars of iron, and many other ingenious mechanical appliances. Incidentally, the primitive process referred to did not result in melting the ore, the iron being removed from the furnace in the form of a plastic mass which contained much less carbon and silicon than the pig iron produced at the present time, and which was adapted for forging; consequently, the process was practically that of producing wrought iron directly from the ore.

In the operation of a modern blast furnace, the furnace proper is charged with a suitable mixture of ore, fuel (usually coke), and a flux; heated air is forced through the "charge" by blowing engines, and the ore is melted as the oxygen of the air causes combustion of the carbon. The melted iron, as it is drawn from the furnace, is run into molds and cast into bars called "pigs" or "pig iron," which is used by foundries in making castings and, by subjecting it to various processes, for producing wrought iron and all grades of steel, from ordinary structural steel to the finest quality used for edged tools. The section on BLAST FURNACES, Vol. I, p. 377, includes the development of the blast furnace, a description of a typical form, materials used in blast furnace construction, method of operating a blast furnace, general information on the fuels and fluxes used, blast furnace troubles, methods of drying and heating the blasts of air, and the modern practice of utilizing blast furnace gas for the generation of power.

Pig Iron. — The pig iron, which is obtained directly from the ore by means of the blast furnace, is divided into various classes, graded either according to its composition, the process to which it is to be subjected, or the method of producing the pig iron itself. Detailed information regarding the various grades of pig iron will be found in Vol. V, p. 21. In this section, the various commercial names are defined and information is given regarding the chemical properties and uses of various grades. The effect of such elements as silicon, sulphur, manganese, and phosphorus in pig iron are also explained.

Wrought Iron and Steel. — Before the introduction of modern methods of producing steel, there was a marked distinction between wrought iron and steel, but at the present time some grades of steel are so similar to wrought iron that the distinction is less pronounced. While iron is the principal element in both wrought iron and steel, the properties and characteristics of both depend upon the small percentages of carbon and other elements combined with the iron and the processes to which the metal has been subjected. Wrought iron, if heated red hot and suddenly cooled, does not harden; formerly, steel was defined as any combination of iron and carbon that would harden if heated sufficiently and then suddenly cooled. This definition, if applied at the present time, would exclude most of the steel now manufactured, owing to the fact that the Bessemer and open-hearth processes produce large quantities of steel, for structural and other purposes, so low in carbon content that sudden cooling will not result in hardening it. Because of this close relationship between wrought iron and some grades of steel, and owing to the fact that wrought iron is the basis of all steel, the student should obtain a clear understanding of the distinction between wrought iron and steel and a knowledge of the general processes of producing them in the various grades now obtainable.

Production of Different Kinds of Iron and Steel. — The section on IRON AND STEEL, Vol. IV, p. 78, was prepared to give a general idea of the difference between various kinds of iron and steel, both with reference to their chemical and physical properties and the processes of manufacture. The section covers the essential and most important facts relating to the properties of iron, the manufacture of wrought iron, the difference between wrought iron and low carbon steel, the production of steel by the Bessemer, open-hearth, and crucible processes, and also contains general information on steel castings, alloy steels, cast iron, malleable castings, and other subjects of importance. In conjunction with the study of this subject, the student should obtain more complete information on the methods of producing iron and steel by reading the following sections: WROUGHT IRON, Vol. VI, p. 555; WROUGHT IRON MANUFACTURE, Vol. VI, p. 558; BESSEMER PROCESS, Vol. I, p. 350; CRUCIBLE STEEL, Vol. 11, p. 271; CRUCIBLES, Vol. II, p. 269; and OPEN-HEARTH PROCESS, Vol. IV, p. 506.

Rolling Mill Practice. — One of the important branches of iron and steel manufacture is that which has to do with the production of bars, rails, or flat plates from the rough heavy ingots obtained from the puddling furnace in the case of wrought iron, or by means of either the Bessemer, open-hearth, or crucible processes, in the case of steel. These ingots are reduced, lengthened, and given whatever shapes are adapted to various industrial purposes, by a mechanical operation involving the use of rolling mills. When bars, rails, plates, etc., are formed by rolling out comparatively short thick ingots, the latter must be hot enough to be reduced readily by the rolling mill. Many flat plates which have been rolled while hot are afterwards "pickled" to remove the scale, and are then given a bright smooth finish by a cold-rolling operation. Shafting, such as is used in mills and factories, is also given a smooth finish after rolling, but this is done by a cold-drawing process, and not in a rolling mill, as many suppose.

General information on rolling mills of various types, rolling operations, rolling mill products, and the power required for driving rolling mills, will be found in the section ROLLING MILL PRACTICE, Vol. V, p. 282. The special section on electric drives for rolling mills, Vol. V, p. 284, should also be read, owing to the extensive use of motors for this work at the present time. The design or formation of the grooves in the rolls used for producing bars, structural shapes, etc., is taken up in the section on BILLETS AND BAR PASSES, Vol. I, p. 369. The sections on ROLL TURNING, Vol. V, p. 287, and ROLL GRINDING, Vol. V, p. 278, contain general information on the methods of making rolls.

The section COLD-ROLLED SHEET STEEL, Vol. II, p. 157, explains what equipment is used for producing flat steel plates having a bright smooth finish, and outlines the entire process from the preliminary annealing operation to the finishing and polishing of the cold-rolled sheets. In connection with this subject, the article on CHANNELING, Vol. II, p. 78, should be read, as this deals with the formation of sheet metals into irregular sections for the manufacture of metal furniture, steel cars, automobile rims, etc.

Wire Drawing. — While bars of iron or steel are produced by a rolling process, this is not a practicable method of reducing bars down to what is known as "wire." In the manufacture of wire, rolled bars are still further reduced in diameter and greatly increased in length by drawing them through series of dies which successively decrease in diameter; for information on wire drawing, see Vol. VI, p. 510. This same general process is applied to larger bars of round, square, or other shapes to obtain a smooth finish, accurate dimensions, and an improvement in the physical properties of the surfaces of bars (see COLD DRAWING, Vol. II, p. 147). For drawing very fine wires, dies made of diamonds are used, owing to their extreme hardness and resistance to wear. In forming the small holes in these dies, which may be 0.001 inch or even less in diameter, considerable skill is required (see DIAMOND DIES, Vol. II, p. 308). The ROD CASTING MACHINE described in Vol. V, p. 272, represents a special development related to the manufacture of wire. (See also WIRE ROD, Vol. VI, p. 519.)

Properties of Iron and Steel. — The elements which enter into the structure of iron and steel greatly affect their physical properties and their value for industrial purposes. As steel has largely replaced wrought iron as a material for general manufacturing purposes and in the construction of buildings, bridges, tools, etc., and as steel is made in a great variety of classes and grades, a relatively large number of articles will be found throughout the ENCYCLOPEDIA dealing with steel, and the chemical and physical characteristics of the various commercial classes now produced. Carbon is the most important element in any kind of steel, but there are many other elements, each of which has its own distinctive effect on the characteristics and properties of the metal. This effect, however, is greatly modified by the relative percentages of the other elements, which may be present in an almost endless variety of combinations. The chemical laboratory is indispensable to the steel manufacturer, not only in analyzing the finished product, but in the selection of raw materials and in controlling various metallurgical processes.

Structural, Carbon and Alloy Steels. — In studying the chemical and physical properties of steel, there are three general classes which should be considered. These classes are designated as low-carbon or structural steel (made by the Bessemer and open-hearth processes); crucible or high-carbon steel (frequently referred to as carbon steel); and alloy steel. Reference should be made to the articles on STRUCTURAL STEEL, Vol. VI, p. 111, and CARBON STEEL, Vol. I, p. 557, for general information on the chemical and physical characteristics of steel, both of the class used for building and bridge construction and the kind used for making edged tools capable of hardening. While carbon is the chief element in all steel, the addition of small quantities of certain other metallic elements results in wonderful changes in the properties of the steel. Alloy steels are made in this way (see ALLOY STEELS, Vol. I, p. 75, and also the special articles on VANADIUM STEEL, Vol. VI, p. 416; TITANIUM STEEL, Vol. VI, p. 290; MANGANESE STEEL, Vol. IV, p. 320; NICKEL-CHROMIUM STEEL, Vol. IV, p. 490; and NICKEL STEEL, Vol. IV, p. 495). Owing to the extensive use of alloy steel in connection with various classes of machine tools, a special section on HIGH-SPEED STEEL, Vol. IV, p. 1, has been prepared.

Properties of Wrought Iron. — Wrought iron or "puddled iron" is still preferred for some purposes, although it has been largely superseded by mild steel. Its use, in many cases, may be ascribed either to the natural tendency to avoid changes, or to the fact that it may be welded very easily. Wrought iron is used extensively by country blacksmiths and is also employed for making chains and hooks for hoisting appliances. One important application is in the use of wrought iron for making tool steel by the crucible process. In this case, wrought iron is used instead of mild steel, because manganese and other undesirable elements can be more easily removed from the iron. As wrought iron is more ductile than mild steel, it is also used quite extensively for making rivets, horseshoe nails, and other articles requiring ductility. The puddling process described in one of the articles previously referred to is the method of producing practically all of the wrought iron manufactured. In the article on WROUGHT IRON, Vol. VI, p. 555, information is given on the characteristics of wrought iron, its physical properties and strength, and the results of tests as applied to different grades.

Properties of Iron and Steel Castings. — When iron is not malleable, or cannot be drawn out or bent to different forms even though heated, it may be classified as cast iron. This term also indicates that the part known as a "casting" is formed by first melting, and at the same time refining, the metal, which is then poured into molds of suitable shape. As cast iron is used universally in the manufacture of a great variety of products, including practically all classes of machinery, its composition and physical properties should be thoroughly understood, especially by the draftsman or designer. The article on CAST IRON, Vol. II, p. 32, deals with the influence of carbon, silicon, sulphur, manganese, phosphorus, and other elements on the quality of cast iron, and also contains general information on its composition, strength, and its industrial applications. Steel castings have replaced the ordinary iron castings in many lines of manufacture, especially when machines are subjected to heavy loads and shocks; steel castings are stronger than either wrought iron, cast iron, or malleable castings (see CASTINGS, STEEL, Vol. II, p. 30).

A great many small castings are made of bronze or brass alloys, instead of from iron or steel, especially where parts are subjected to corrosion, as in the case of pipe fittings, etc. General information regarding the alloys used in brass foundry practice will be found in Vol. I, p. 494, in the section on BRASS FOUNDRY PRACTICE.

If ordinary white iron castings are subjected to a special heat-treatment, they may be made much less brittle and, to some extent, malleable; in fact, malleable cast iron may be bent or twisted, and it is much superior to ordinary castings for withstanding repeated shocks. The composition of malleable castings as recommended by the Society of Automobile Engineers will be found in Vol. IV, p. 306, in the section on MALLEABLE CASTINGS.

HEAT-TREATMENT OF IRON AND STEEL

PARTS made of steel often require some form of heat-treatment in order to change the chemical and physical properties, and thus make the steel either softer or harder than it is after leaving the steel-maker. Wrought iron or cast iron may also be given some form of heat-treatment. The various processes applied to different kinds of steel, however, will be considered first, since they are the most important. The general practice of heat-treating steel has been greatly improved and modified within the last two decades, especially since the introduction of alloy steels. The object of heat-treatment is usually to increase the degree of hardness (although in some special cases the purpose may be to soften the metal so that it can be cut more easily) or to increase its ductility.

Hardening, Tempering, and Annealing. — The heat-treatment processes may be divided into three general classes — annealing, hardening, and tempering. Annealing softens the metal, removes internal strains, and prevents, partly at least, subsequent warping. The principal reason for hardening may be to give the part greater wearing qualities or, in the case of a tool, to make it capable of cutting other materials. The tempering process reduces the brittleness of hardened steel, but makes it somewhat softer. The exact method of annealing, hardening, or tempering may depend upon the size of the work or the quantity and the grade of steel. A knowledge of these different heat-treating processes will prove of value to men engaged either in the design or construction of machinery. The designer who understands what can be accomplished by proper heat-treatment methods can often economize in the use of materials by specifying a comparatively cheap grade of steel, which, by proper heat-treatment, is made suitable for the particular service required. The man engaged in the actual work of machine construction, even though he may not be directly concerned with the various heat-treatment processes, will find that a general knowledge of them is frequently of considerable practical value.

Different methods of annealing are described in a special article on this subject in Vol. I, p. 99. The section on HARDENING AND TEMPERING, Vol. III, p. 512, includes general information on the different types of furnaces and liquid baths commonly used for heating steel preparatory to hardening; the baths used for cooling the heated steel quickly in order to harden it; and the different methods of tempering. This article also contains a complete explanation of the changes that occur in the composition and structure of the steel incident to heating and cooling. This explanation of the theory of hardening and tempering will enable the student to more readily understand the effects obtained by different processes of heat-treatment.

The quality of the high-speed or alloy steels used for metal-cutting tools may be greatly affected by the heat-treatment, and, as a general rule, it is advisable to follow the directions given by different steel-makers. The general practice in hardening and tempering steel of this class, however, is described in the section on HIGH-SPEED STEEL, Vol. IV, p. 2. The heat-treatment of alloy steels is dealt with in detail in the article ALLOY STEELS, Vol. I, p. 75.

Determining Hardening Temperatures. — In the heat-treatment of any grade of steel, the controlling factor is the temperature. For instance, in order to harden ordinary crucible steel, it must be heated above a certain temperature, but, if the temperature is too high, the quality of the steel may be seriously affected. While it is important to know what the hardening temperature should be, it is also essential to have some positive means of determining when the work is heated to this desired temperature. In well-equipped hardening plants, instruments called "pyrometers" are used for this purpose. The most important types used in connection with the heat-treatment of steel are described in the section on PYROMETERS, Vol. V, p. 217. Information is also included on the methods of testing or calibrating pyrometers in order to insure accurate temperature readings. Pyrometers in good condition make it possible to secure more uniform results in the heat-treatment of steel than could be obtained in any other way.

Casehardening and Pack-hardening. — When wrought iron or a low-carbon steel needs to be hardened, this cannot be done by heating the part above a certain temperature and then cooling it suddenly, as in the case of crucible steel. If the wrought iron or low-carbon steel, however, is heated while in direct contact with some material rich in carbon, the outer surface of the metal will absorb some of this carbon, so that it can be hardened by the usual method. This process is commonly known as "casehardening," and is especially applicable when a machine part should have a hard outer surface to resist wear, and a relatively soft, but tough, interior that is not brittle and liable to be broken by shocks. The section on CASEHARDENING, Vol. II, p. 2, explains the various applications of the casehardening process. This section also deals with local hardening, or the method of hardening at only one place, the other parts being left soft. The article on ENAMELITE, Vol. III, p. 57, is also descriptive of a method of local hardening by using a special preparation or compound.

The pack-hardening and casehardening processes are similar, and, while these terms are often used interchangeably, pack-hardening is generally understood to mean the treatment of a high-carbon or tool steel, the surface of the steel being impregnated with additional carbon, so that it may readily be hardened by quenching in oil, as described in the article on PACK-HARDENING, Vol. IV, p. 514.

Heat-treatment of Gears. — The life or durability of the steel gears now used extensively in the drives of machine tools and in automobile transmissions may be greatly increased by proper heat-treatment. Owing to the importance of this subject, it has been treated in a special section in Vol. III, p. 374; this article covers annealing methods; carburizing processes such as are required for low-carbon steel; the tempering of hardened gears; the kinds of steels to use for hardened gears, with specific information on temperatures, etc., for steel of different grades.

Tests for Hardness. — In many lines of manufacture requiring the use of hardened steel parts, it is important to know what degree of hardness has been obtained by heat-treatment. While great improvements have been made in hardening methods, it is not possible to harden duplicate parts with any certainty that they will all possess the same degree of hardness; in fact, there are often decided variations even when attempts are made to secure uniform results, owing to changes of temperature either in the furnace or quenching bath, or in the chemical composition of the steel. There are, therefore, various reasons why the hardness of steel parts should be tested. The object may be to determine whether a surface is hard enough to resist abrasion and wear; whether a cutting tool is hard enough to perform the required work; or whether there is excessive hardness and resulting brittleness, which might cause the part to break when in service. Instruments and methods of testing the hardness of metals which have been employed in actual practice include the sclerometer, the scleroscope, the Brinell indentation test, and the Keep drill test. The section on HARDNESS TESTING, Vol. III, p. 527, describes the different instruments and the methods of making these tests.

Microscopic Examination of Steel. — The microscope is now used by many metallurgists for examining the structure of steel, and it has proved to be a valuable adjunct to the chemical laboratory for determining the quality and characteristics of various kinds of steel, as they may be affected by manufacturing processes or subsequent heat-treatment. This application of the microscope to the study of steel structure and composition is usually known as "metallography." A complete treatise on this subject will be found in Vol. IV, p. 348, covering the methods of preparing specimens to be examined; the etching of the polished surface to reveal the internal structure of the metal; etching reagents, both for nonferrous metals and for iron and steel; and other important points relating to this effective method of studying the structure of metals by direct observation. The application of metallography to case-hardening is dealt with in Vol. II, p. 7.

Furnaces. — The results of any heat-treating process may depend largely upon the type of furnace used for supplying the necessary heat, and it is essential to know the classes of work for which different types are adapted. The design of furnaces, in general, depends upon whether the heat is derived from some fuel or from an electric current, and also upon the size and proportions of the parts to be heated, as well as the importance of careful heat-treatment. When steel is heated to a high enough temperature for hardening, it readily absorbs injurious elements that may be present and is also subject to oxidation or the formation of scale on the surface. Some furnaces, especially of the types intended for heating high-grade tools preparatory to hardening, are arranged to avoid difficulties from oxidation or from the injurious elements that may be liberated by combustion. The practice of heating some parts by immersing them in a molten bath, and others in a heated chamber or oven, also causes variations in furnace construction and operation. The article on FURNACES FOR HARDENING AND TEMPERING, Vol. III, p. 256, describes furnaces of various classes, such as gas-heated furnaces, oil-burning furnaces, solid fuel furnaces, and electric furnaces. Some furnaces intended especially for heat-treating processes are also described in the section on FURNACES, Vol. III, p. 220, which covers general types. The special article on ELECTRIC FURNACES, Vol. III, p. 240, should also be studied if the subject is to be thoroughly covered.

NONFERROUS METALS AND ALLOYS

WHEN two or more metals are melted together and thus combined to form what is practically a new metal, at least so far as its properties are concerned, this combination is known as an "alloy." So-called "ferrous" alloys contain iron as the chief element; "nonferrous" alloys have some other metal as a basis. Copper, with the single exception of iron, is the most important metal used in connection with engineering work. Copper forms the basis of brass and bronze alloys, and is practically indispensable in the construction of electrical machinery and as a means of transmitting electric current; in fact, it is second only to silver as a conductor of heat and electricity. Copper also resists corrosion to an unusual degree and is used both in sheet form and in the shape of pipes or tubes in the construction of a great variety of apparatus in which noncorrosive parts are of especial importance. Among other important metals which are extensively used in producing various kinds of alloys for industrial purposes may be mentioned tin, zinc, lead, aluminum, and nickel. The different alloys which may be produced by combining two or more of these metals in varying proportions are innumerable, and vary as much in their application to industrial purposes as in their composition. The subject of alloys, in general, is covered in the section on ALLOYS, Vol. I, p. 66, which deals with the different classes, the kinds of metal used in producing them, the relative percentages of different metals, the defects common to alloys used in machine construction, and the adaptability of alloys to different commercial purposes.

Copper. — As copper is the chief element in a great many of the nonferrous alloys, it is dealt with in a separate article (Vol. II, p. 204) which describes different methods of smelting copper and contains important data on the composition of copper alloys, their melting points, etc. In connection with this subject, it is advisable to read the article on ELECTROLYTIC REFINING OF METALS, Vol. III, p. 33, which deals principally with copper refining.

Copper castings are used to some extent, especially in connection with electrical work, but it has not been practicable until quite recently to obtain such castings that were not very porous. By the use of boron, which has a high affinity for the gases that cause the difficulty in copper castings, these defects have been overcome. (See COPPER, BORONIZED, Vol. II, p. 207.)

Brass. — Brass is more extensively used than any of the other nonferrous alloys. It is composed principally of copper and zinc, and may contain small percentages of other metals such as lead, iron, or tin. The information in the section on alloys is supplemented by a special article on BRASS, Vol. I, p. 490. Reference should also be made to the article on MUNTZ METAL, Vol. IV, p. 485, and MANGANESE-BRONZE, Vol. IV, p. 318; while the term " bronze " is applied to the latter alloy, it should properly be classified as a "brass," as copper and zinc are the basic metals in its composition. DELTA METAL, Vol. II, p. 304, is another copper-zinc alloy which is made very strong by the addition of a small amount of iron.

Bronze. — The alloys classified as "bronze" are composed principally of copper and tin, and may contain small percentages of other elements, such as zinc, antimony, lead, aluminum, phosphorus, or manganese. Phosphor-bronze is one of the important alloys of this class, as it is extensively used for machine bearings and in the manufacture of springs, worm gearing, etc. This alloy derives valuable properties from the small amounts of phosphorus it contains, which increases the tensile strength, ductility, and resistance to repeated stresses or shock. (See BRONZE, Vol. I, p. 517, and PHOSPHOR-BRONZE, Vol. V, p. 12, and, in addition, the following special articles: GUN-METAL, Vol. III, p. 488; TOBIN BRONZE, Vol. VI, p. 292; and LUMEN BRONZE, Vol. IV, p. 266.) Some alloys commonly designated as bronze do not have copper and tin as the basic metals, as, for example, the copper-aluminum alloys referred to in the section on alloys.

White Metal Alloys. — The general class of nonferrous alloys formed of the softer and more fusible metals, such as tin, lead, zinc, and antimony are extensively used in various industries. General information on the basic metals used for making alloys of this class will be found in the following articles: TIN, Vol. VI, p. 288; LEAD, Vol. IV, p. 193; ZINC, Vol. VI, p. 563; and ANTIMONY, Vol. I, p. 102. The soft solder used by plumbers and tinners is an important white metal alloy of the tin-lead class. (See SOLDER, Vol. V, p. 386.) Britannia metal, which is used extensively for manufacturing silver-plated ware, is a tin-antimony alloy of considerable commercial importance. (See BRITANNIA METAL, Vol. I, p. 506.) Fusible metals or alloys that will melt at a low temperature are used in the heads of automatic sprinklers and in making fuses for electrical circuits and fusible plugs for steam boilers. (See FUSIBLE METALS, Vol. III, p. 268; and MELTING POINTS OF METALS, Vol. IV, p. 334, which give the melting temperature for a large range of fusible metals.)

Bearing Metals. — It might well be said that a machine is no better than its bearings, and this fact is now generally recognized by machine manufacturers. Bearing metals are made in an almost endless variety of compositions, and quite a number of these are patented. The basic metals are usually copper, lead, tin, antimony, and zinc, two or more of these metals being used to form an alloy. The article on BEARING METALS, Vol. I, p.

296, gives the composition of a great variety of alloys and includes general information on the requirements of bearing metals, the results of tests, etc. One of the oldest and most extensively used alloys for bearings is known as " babbitt " metal. Owing to the commercial importance of this alloy, it is dealt with completely in a separate article on BABBITT, Vol. I, p. 198. The methods of applying this metal to bearings are explained in the section on BABBITTING BEARINGS, Vol. I, p. 199.

Aluminum. — It has been estimated that aluminum in its various compounds forms about one-twelfth of the crust of the earth. The specific gravity of pure aluminum is only about one-third that of iron, and this extreme lightness combined with unusual strength when alloyed with a small percentage of some metal such as copper, manganese, iron, or nickel, are the physical properties which have made aluminum of such importance in many lines of manufacture. The article on ALUMINUM, Vol. I, p. 83, deals with its properties, strength, industrial applications, methods of production, and methods of jointing aluminum. MAGNALIUM, Vol. IV, p. 287, is one of the most important of the aluminum alloys, the principal application of which is in connection with aeronautic motor manufacture.

Nickel. — Nickel is malleable and weldable like iron, but differs from the latter metal in that it does not oxidize readily, nor deteriorate rapidly under atmospheric influence. It is used extensively for protecting iron and steel parts and improving their appearance by the nickel-plating process, and, within recent years, it has been utilized in the manufacture of high-grade alloy steels. (See NICKEL, Vol. IV, p. 489.) MONEL METAL, Vol. IV, p. 429, is a nickel-copper alloy that is one of the most remarkable of the metal alloys.

Rolling, Drawing, and Extruding Operations. — Nonferrous metals and alloys such as copper, brass, or bronze are rolled into bars and sheets and are used in the manufacture of tubes and wire, the same as iron and steel. Castings of a simple form are first made, and are then rolled into flat sheets or drawn to form tubes or wire. The article BRASS ROLLING MILL PRACTICE, Vol. I, p. 497, describes the preliminary work of making these castings and contains general information on the equipment used for rolling flat sheets, bars, or rods, and for drawing seamless tubes. Reference should also be made to the article on WIRE DRAWING, Vol. VI, p. 510.

One of the most interesting methods of forming rods or bars of different cross-sectional shapes is known as the "extrusion" process. With this process, the metal. which must be fairly plastic, is forced through an aperture of the cross-sectional shape required by subjecting the metal to a very high pressure, thus forming a continuous rod or bar. At first the extrusion process was only applied to lead; later lead-tin alloys were used, and, as the apparatus was still further perfected, it was found practicable to extrude other nonferrous alloys. A complete treatise on the EXTRUSION OF METALS will be found in Vol. III, p. 77, which deals with the historical development of the extrusion process, various types of extrusion presses, and the metals adapted to extrusion.

PRODUCTION OF CASTINGS

MACHINES and mechanisms of all kinds consist of assembled parts that are, in practically all cases, formed partly or entirely by a casting process, by forging, by cutting, by the application of pressure between dies, or by two or more of these methods combined. Castings are parts formed to shape by pouring molten metal into a suitable mold; they are used very extensively and are indispensable for machine frames, beds, and other parts which serve as a support for the mechanism. Many small parts are also cast, and the development of new and improved machinery and processes has made it possible to produce small castings rapidly and with such accuracy, that machining operations are, in some cases, partly or entirely eliminated. The great advantage of the casting process is that it enables parts of almost any desired form to be produced. In fact, a great many shapes or forms are obtained by casting that could not be forged from wrought iron or steel.

Procedure in Making a Casting. — The usual method of producing a casting requires, first, a drawing of the casting; second, a pattern which corresponds to the external form of the casting; third, a mold or cavity which receives its shape from the pattern; and, fourth, means of melting metal so that it can be poured into the mold. The drawing represents the work of a draftsman or designer; the pattern is made by a patternmaker; the mold, by a molder; and the molten metal is supplied by the foundryman, who requires a practical knowledge covering the operation of the melting furnace or cupola and the kinds of raw materials to use, in order to obtain castings having the right composition and physical characteristics or properties. While these are separate branches of work requiring special training or skill, they are closely related in many respects. The student of machine design may not consider it important to understand the principles of patternmaking, but, since the design drawn on paper must be reproduced in the form of a pattern, it is evident that a draftsman who knows nothing of patternmaking may cause considerable unnecessary work in the pattern shop, or give the patternmaker a task in woodworking which is almost impossible. There is also a close relationship between patternmaking and molding; in fact, a good patternmaker must understand, thoroughly, the principles of molding, and it is well for the designer to possess at least a general knowledge of both of these branches of work.

Patterns and Patternmaking. — As most patterns are made of wood, and as many of the forms required are quite intricate, patternmaking requires a high degree of skill in woodworking. In dealing with this subject in the ENCYCLOPEDIA, the aim has been to explain the fundamental principles of patternmaking, rather than to teach the exact procedure in the actual work of making patterns. (See Vol. IV, p. 531.) Different types of patterns have been classified, as far as possible, and the relation between different forms of patterns and the molds made from them is explained, because all pattern construction depends upon the method of making the molds in the foundry. The patternmaking section also includes general information on materials for patterns and approved methods of making joints and building up different forms common to pattern construction. (See also WOOD TURNING TOOLS, Vol. VI, p. 540; BAND SAW SPEEDS, Vol. I, p. 243; and the section on ELECTRIC DRIVE FOR WOOD-WORKING MACHINES, Vol. IV, p. 439.)

Making Molds for Castings. — The formation of molds for producing castings of different forms involves a study of the relation between the type of mold and the casting required, the materials used for molds, and the equipment employed in various branches of the molding process. The practice of molding has changed considerably within recent years, especially with regard to the use of mechanical apparatus for making molds and for producing duplicate castings by special machines designed for that purpose. The section on MOLDING, Vol. IV, p. 411, deals with the three general branches of molding, which are known as green-sand molding, dry-sand molding, and loam molding. The practical application of these different methods is shown by numerous examples from practice.

As many castings must have interior passages or openings which could not be formed in the mold by a pattern, cores conforming to the required shape are inserted in the mold after the pattern is withdrawn. For specific information on the composition of cores, see CORE MAKING, Vol. II, p. 208, and also the article on MOLDING SAND, Vol. IV, p. 427. General information on the different types of machines now extensively used in modern foundries, to eliminate the manual labor connected with molding and to reduce the time required, will be found in the article on MOLDING MACHINES, Vol. IV, p. 422. If many duplicate castings are needed, a permanent mold made of metal may be used instead of the ordinary sand mold which can only be used for one casting, as explained in the article CASTING IN PERMANENT MOLDS, Vol. II, p. 20.

Operation of a Foundry. — Foundry practice, aside from the work of molding, involves melting the metal that is to be used for making castings. This is really a re-melting operation, since the raw material has been obtained from the ore by a previous melting process, the pig iron used for making iron castings being a product of the blast furnace. It is necessary for the foundryman to know how to obtain different grades of castings by using different qualities of pig iron and by charging the cupola or furnace with different mixtures of pig iron and scrap iron. Other questions that arise in foundry practice relate to the amount of fuel to use in the cupola and the method of distributing it, the weight of iron for a given charge, and the quality and kind of flux to use for forming a slag and protecting the bath of molten metal. The article on FOUNDRY PRACTICE, Vol. III, p. 210, is in the nature of a general review, and is supplemented by separate articles covering the more important branches of foundry practice. The general arrangement and operation of the cupola furnace, which is the type most commonly used, as well as the composition of castings intended for different purposes, is explained in the article on CUPOLAS, Vol. II, p. 275. In this connection, the sections on CASTINGS, IRON, Vol. II, p. 26, and CAST IRON, Vol. II, p. 32, should also be studied, if this has not already been done in connection with some other course. The final foundry operation on castings is the cleaning and pickling, covered in the articles PICKLING CASTINGS, Vol. V, p. 19, and SAND-BLAST, Vol. V, p. 307.

Control of Casting Processes. — The quality and physical properties of castings may be affected and controlled to a considerable degree by the condition under which castings are made. For instance, unsound castings, or those containing blow-holes, may be obtained if the mold is not in the proper condition or is not adequately vented to allow the steam and gas generated by the heat from the molten metal to escape. The decomposition in the binder of the cores, the entrapping of air, the formation of shrink-holes, sponginess, and scabbiness are other difficulties encountered. This general subject is dealt with in the article on CASTINGS, IRON, Vol. II, p. 26. A feature of this article of essential importance to designers is that dealing with shrinkage strains. When a heavier section adjoins a lighter one, the latter naturally solidifies first as the metal cools in the mold and is subjected to a strain when the heavier section cools and contracts. In some cases, these internal stresses may seriously reduce the effective strength of the part; they also cause many castings to spring or warp slightly after being machined.

For some purposes, very hard castings, or castings having very hard surfaces, are needed, the wheels used for railroad cars being an example. The way in which a hard outer surface is obtained is explained in the article CHILLED CASTINGS, Vol. II, p. 98. Ordinary iron castings are rather brittle and are liable to break if subjected to shock. By a special heat-treatment, however, iron castings may be made tougher and somewhat malleable. Such castings are known as MALLEABLE CASTINGS, Vol. IV, p. 306.

Steel Foundry Practice. — Steel castings have replaced ordinary iron castings on many classes of machinery, especially when heavy loads must be supported or there are sudden thrusts and shocks when the machine is in operation. The steel may be made by the Bessemer, open-hearth, or crucible process, the charge being composed principally of steel scrap with a certain proportion of pig iron. The general methods of producing steel castings are explained in the article STEEL FOUNDRY PRACTICE, Vol. VI, p. 66. Specific information on the properties and composition of steel castings may be obtained from a special article CASTINGS, STEEL, Vol. II, p. 30.

Brass Foundry Practice. — The production of castings from brass or other nonferrous metals is similar in principle to the process of making iron castings, although there is a difference in the equipment used. The molding is done in practically the same way, except for changes due to the fact that the average brass casting is much smaller and is molded in a finer grade of sand. The common types of melting furnaces used in brass foundries differ from the cupola of the iron foundry. The section on BRASS FOUNDRY PRACTICE, Vol. I, p. 491, is a condensed treatise intended to give the student a general survey of this subject. ZINC CASTINGS, Vol. VI, p. 567, are sometimes produced in the brass foundry, although they are only used in a very limited way. The melting furnaces used in brass foundries are dealt with in detail in the article FURNACES, Vol. III, p. 220; an electric brass melting furnace is described in Vol. III, p. 255.

Die-casting Process. — The art of die casting, or the formation of metal parts by casting in metal molds, has been applied to certain processes for many years, but represents a distinctly modern development as a means of producing many small machine parts economically and with such accuracy that machining operations may be entirely unnecessary. While parts made of steel are inexpensive so far as the cost of material is concerned, if the cost of machining and of other operations is taken into consideration, parts made by the die-casting process may be much cheaper. The production of die castings requires a metal mold of suitable form and means for melting the metal and forcing it into the mold. The various classes of die-casting machines are described in the section on DIE CASTING, Vol. II, p. 314, which includes information on different types of dies, the advantages of the die-casting process and its application, and the composition of the different nonferrous metals which are adapted to this method of casting production.

Die-pressed Castings. — The production of die-pressed castings (Vol. II, p. 359) is another recent development, intended primarily to produce duplicate parts which are uniform in size and nicely finished, without a machining or metal-cutting operation.

FORGING PRACTICE AND EQUIPMENT

WHEN wrought iron or steel is heated and formed to whatever shape required, either by hammering or by the application of pressure, the operation is known as "forging." Many machine parts are forged and used in preference to ordinary iron castings, because they are much tougher and less liable to fracture when subjected to shock. Parts may be forged roughly to the approximate shape required, so that the amount of metal to remove by turning, planing, or milling, or some other machining process is greatly reduced, or the forgings may be finished so accurately by means of special equipment that little or no machining is necessary. While the making of forgings is a hand-hammer or sledge and anvil process in many small shops, numerous developments have been made in forging methods, especially in machine-building plants or wherever large numbers of duplicate forgings are used. For many years the inventor rarely took any interest in the blacksmith or forge shop; now the sharp rapid blows of power hammers, drop-hammers, and forging machines are heard in many forging departments instead of the ringing anvil. The smith with his hand-manipulated tools is still indispensable for certain classes of work, but modern forging machinery has invaded his domain and made it possible to produce high-grade forgings by very efficient and economical methods.

Forging Processes and Tools. — The way in which a forging is made depends usually upon its size and the number of duplicate forgings required. The simplest and most primitive method of forging is by means of a hand hammer or sledge and an anvil, in conjunction with tools of special form for shaping curved and flat surfaces, or for cutting and trimming forgings. The laborious work of hand forging has been largely eliminated by the use of power hammers, especially for the larger classes of work, and many special forging machines are now in use. A brief general review of forging practice is given in the article on FORGING, Vol. III, p. 186, and the small tools and appliances used in connection with hand-forging operations are dealt with in the article on BLACKSMITHS' TOOLS, Vol. I, p. 372. The following articles should also be studied in this connection: FORGES, Vol. III, p. 177; ANVILS, Vol. I, p. 102; and FORGE SHOP ARRANGEMENT AND EQUIPMENT, Vol. III, p. 180.

Power Hammers and Forging Presses. — Hammers which are operated by power are practically a hammer and anvil combined, and, as they are capable of striking powerful blows in rapid succession, their use permits a forging to be quickly reduced to the desired form. Hammers of this class are made both for small, light forging operations and for very heavy work. Some hammers are driven by belt and others by the direct application of steam or air pressure. Typical designs are described in the article relating to power and steam hammers, Vol. III, p. 498. This article also explains a method of determining the efficiency of forging hammers. In plants where very large forgings are made, forging presses are commonly used instead of steam hammers. These presses may be either of the plain hydraulic type or of the steam-hydraulic design. The article on FORGING PRESSES, Vol. III, p. 189, explains the operation and application of forging presses, as well as their advantages as compared with steam hammers.

Forging Machines. — The use of forged parts made either from wrought iron or different grades of steel, in preference to iron or steel castings, has been made possible, in many manufacturing plants, by the development of special forging machines. The modern upsetting and forging machine is a development of the bolt and rivet header originated many years ago. The forging machine, however, is much heavier and is designed particularly to produce machine forgings in large quantities. Machines of this class must be arranged for each particular operation, as special dies are required to give the forgings the required form or shape. (See FORGING MACHINES, Vol. III, p. 187.) One of the important applications of special forging machinery is in the manufacture of bolts and nuts. For general information on this subject, see BOLT FORGING, Vol. I, p. 450, and NUT FORGING, Vol. IV, p. 498.

Production of Drop-forgings. — The hand-manipulated forming tools used by blacksmiths for shaping curved and flat surfaces doubtless suggested the application of dies to the forging of duplicate parts. A cavity or impression is formed in the upper and lower sections of a die, which conforms to the shape of the forging to be made, and when the upper die, which is attached to a heavy hammer head, is allowed to fall, the heated bar of metal placed between the dies is forced into the upper and lower cavities and is given the required form. This method has been applied very extensively to the production of small and medium-sized forgings. As special dies are needed for forgings of different shapes, the design and making of these dies is a most important branch of drop-forging practice. The article on DROP FORGING, Vol. II, p. 474, covers the subject in a general way. The making of drop-forging dies, which is known as "die sinking," requires considerable skill as well as experience and judgment regarding the best methods of securing the desired shapes, particularly when more than one impression and forging operation is necessary. This subject is dealt with in the article on DROP-FORGING DIES, Vol. II, p. 484. The special types of hammers used for making drop-forgings are described in detail in the section DROP-HAMMERS, Vol. II, p. 500. The article DROP-FORGING AND HARDENING PLANTS, Vol. II, p. 481, includes general information on the arrangement of such plants and their equipment.

Cold-heading Machines and Operations. — All of the forging operations so far referred to require metal that is heated, so that it can more readily be formed to shape, either by hammering or by the application of pressure. Many small parts of the class made from wire or small rods can be given the necessary shape without a preliminary heating. This method of forming parts when applied to the formation of heads on bolts, rivets, pins, etc., is known as "cold heading," and, while it may not properly be classified as a forging process, is closely allied to it. Cold-heading operations are performed by means of special machines equipped with dies which govern the shape produced. The different classes of machines are described in the article on COLD HEADING, Vol. II, p. 148; this article also explains the principle of the cold-heading process, and includes practical examples of work.

Cold-swaging Process. — The cold-swaging process is another method of forming small parts made from rods, wire, etc., without preliminary heating. Swaging differs from cold heading in that it serves to reduce or otherwise change the form of the work by a rapid succession of blows from dies of suitable shape which operate in a lateral direction relative to the stock and not end-wise, as in cold heading. Information on the application of the swaging process and the types of machines used will be found in the article on SWAGING, Vol. VI, p. 133. The hammering machine may be classified as a special form of swaging machine, although this method of forming rods, wire, or tubing into special and ornamental shapes may be applied to a greater variety of work than the swaging process; these machines are described in the article on HAMMERING MACHINES, Vol. III, p. 497.

STANDARDS AND METHODS OF MEASUREMENT

ONE of the basic principles not only in all mechanical work, but also in our whole commercial life, relates to the taking of measurements or adopting standards for measuring lengths, areas, and volumes. Without commonly accepted standards for measurements, trade would become almost impossible, all interchangeable mechanical work impracticable, and our whole civilization would be in a most primitive state, because it is evident that the standards of weights and measures, and the methods of taking measurements are essential to modern civilized life. It has been ascertained that the ancients, several thousand years ago, had developed standards of length that were quite accurate, because some of the structures erected at that time, that are still in existence, indicate that this was the case. It is only within comparatively recent years, however, that highly accurate standards for weights and measures have been determined and accepted by the various nations, and the methods for accurately reproducing these standards and for taking measurements in practical shop work with a high degree of accuracy are of still more recent origin.

Systems of Weights and Measures. — There are two systems of weights and measures in general use in the civilized world — the *English* system, which is used in the English-speaking countries, and, to a limited extent, in some other countries, and the *metric* system, which is used by the majority of the non-English-speaking civilized nations. In some instances, the metric system is used in the English speaking countries, and other systems than the metric, usually the old systems that have not yet been entirely disestablished, are used in the countries that otherwise employ the metric system. It is possible that the metric system will find increasing use in the future, and, on this account, and also on account of the necessity for understanding the system in connection with the foreign trade, both the English and the metric systems have been dealt with in detail in the ENCYCLOPEDIA. In the article WEIGHTS AND MEASURES, Vol. VI, p. 463, are given tables including all of the generally used measures of lengths, areas, volumes, and weights in the English system, as well as the units employed in the metric system, together with conversion factors for changing English into metric and metric into English units. In addition to these tables of standard units of measurements, the article contains a brief history of the standardization of weights and measures. As the standards of length measurements are of more direct application in the mechanical industries than the standards of other measures and weights, the principles applied in establishing standards of length, and in preserving the originally accepted standards, have been dealt with in greater detail than for other standards in the article STANDARDS OF LENGTH, Vol. V, p. 539. The application of the metric system to practical shop work, the making of drawings in the metric system, tools made to metric measurements, etc., are subjects briefly dealt with in a separate article on the METRIC SYSTEM, Vol. IV, p. 356.

Absolute System of Measurements. — In addition to the ordinary systems of measurements used for ordinary practical work, there is a third system, known as the "absolute system of measurement," which is used for scientific and theoretical work, and which is based primarily upon the metric system, but includes units for all mechanical, physical, and electric quantities not originally contemplated when the metric system was adopted. The absolute system of measurement is also known as the "centimeter-gram-second" system, because its fundamental units are the centimeter, the gram, and the second. (See ABSOLUTE SYSTEM OF MEASUREMENT, Vol. I, p. 6.)

Simple Length Measuring Instruments. — Having established a standard for length, the next step in practical work is to provide means by which this standard can be conveniently employed for taking measurements in the building of machinery and structures. The simplest and most commonly used of all measuring instruments in the mechanical trades is the well-known *scale*. In many instances, however, scales cannot be applied directly to the work. The diameter of a round piece of work, for example, cannot be measured directly by the scale. In cases of this kind, it becomes necessary to provide means for transferring the dimension from the part to be measured to the scale. One of the simplest means of doing this is by the use of machinists' calipers, which may also be set to a certain dimension on the scale and used as a simple kind of gage, that is, as a means for determining whether the size of a piece of work is equal to a predetermined dimension. (See CALIPERS, Vol. I, p. 527.) Ordinary calipers, however, are used only for work which does not require a great degree of accuracy, because extreme accuracy or refinement in measurements is not possible, either by the use of a scale or by means of calipers. More highly developed measuring instruments are required in that case.

Vernier Calipers. — For obtaining more accurate readings when taking a measurement, a measuring device known as a "vernier scale caliper" may be employed. This measuring device permits of considerably greater accuracy in taking measurements than would be possible with a scale and ordinary machinists' calipers. The construction of the vernier caliper and an explanation of the manner in which this instrument is used and how readings are taken from the vernier scale are given in the article VERNIER SCALE AND CALIPER, Vol. VI, p. 437.

A special kind of vernier caliper, known as the "vernier gear-tooth caliper," is used for testing the thickness of gear teeth at the pitch-line. (See Vol. III, p. 323.) This instrument provides a very accurate means for determining whether the proper proportions of gear teeth have been obtained in the cutting processes for forming these teeth. In order to obtain a smooth and quiet action in gearing, it is important that the teeth are properly shaped. Vernier calipers make it possible to determine dimensions within an accuracy of one-thousandth inch.

Micrometer Measuring Instrument. — When the highest degree of accuracy that is generally obtainable in ordinary shop work is required, micrometers, also known as "micrometer calipers," are employed, unless fixed gages are used. Micrometers are precision measuring instruments with which exceptionally accurate measurements can be taken. At the present time, they are universally used in machine-building plants. Without micrometers, many of our highly specialized interchangeable manufacturing plants would hardly have been able to develop the efficient methods which they have applied in their progress. Micrometers are of great value to machinists, and no toolmaker could possibly be without one in his work. They are made in different forms for external and internal measurements. Some of the principal forms are described in the article MICROMETER, Vol. IV, p. 358; instructions for using and reading a micrometer are also given in that article, and several sensitive attachments that may be used in connection with micrometers are described. As the micrometer caliper is one of the most useful tools used in mechanical work, a detailed history of its development has been included in the ENCYCLOPEDIA in the section on MICROMETER DEVELOPMENT, Vol. IV, p. 362.

Precision Measuring Machines. — For the highest precision that is obtainable in practical work, without resorting to the refined methods employed only by scientists, so-called "measuring machines" are used. These are devices of the greatest precision used for comparing and originating standards of lengths and for verifying the accuracy of gages used in manufacturing processes. Measuring machines of well-known types are provided with graduations which read directly to one-ten-thousandth inch, and these divisions can be easily subdivided into four subdivisions by estimating, so that measurements may be taken with an accuracy of 0.000025. Measuring machines for laboratory work are constructed with even higher degrees of precision, one type having been built which is considered absolutely accurate within 0.000004 inch. The general construction of various types of these machines and their application to practical work are explained in the article on MEASURING MACHINES, Vol. IV, p. 327.

In this connection may be mentioned a measuring apparatus known as the "minimeter," which may be considered as a simple type of measuring machine intended as a comparator to indicate differences of small fractions of an inch between the piece measured and a standard gage. The minimeter, when constructed for English measurements, would have graduations reading to one-half thousandth inch, and, by estimating the position of a pointer on the scale, accurate readings within one-ten-thousandth inch are obtainable. (See MINIMETER, Vol. IV, p. 409.)

For scientific measurements of the very highest degree of accuracy, an instrument known as an "interferometer" is used. As this instrument is not ordinarily employed in practical work, but only in scientific laboratories, it has only briefly been dealt with in the ENCYCLOPEDIA. The principles upon which it is based are explained under the heading INTERFEROMETER, Vol. IV, p. 72.

Protractors for Angular Measurements. — All of the measuring devices referred to in the preceding paragraphs are intended for measuring lengths. In mechanical work, however, the measuring of angles, tapers, etc., is frequently necessary, and in some instances it is required to obtain these measurements with considerable accuracy. The general principles involved in the making of angular measurements and the relationship between tapers and angles expressed in degrees and minutes are outlined in the article ANGULAR MEASUREMENTS, Vol. I, p. 96, which also contains a number of formulas for making the calculations that are required in connection with measuring angular work. The laying out of angles, which in shop work is of equal importance to the measuring of angles, is dealt with in an article in Vol. I, p. 94. The measuring tools used in shop practice for determining the sizes of angles in degrees and minutes are known as "protractors," the type generally used by machinists and toolmakers being known as a "bevel protractor." When provided with a vernier scale, measuring instruments of this type will give accurate readings to within five or three minutes (one-twelfth to one-twentieth of a degree). The construction of the bevel protractor and the method of reading the graduations on the protractor scale and on the vernier are explained in the article PROTRACTOR, Vol. V, p. 178. Draftsmen also employ protractors, but of a different kind. They are simpler in construction and frequently are not provided with a vernier scale, as it is seldom necessary to lay out angles on a drawing with the extreme accuracy that is required when working out the angle in solid metal in the shop. Draftsmen's protractors are briefly described in the general article on DRAFTSMEN'S TOOLS, Vol. II, p. 401.

Gages and Gaging Methods. — The measuring instruments and devices used in shop work may be divided into two broad groups, one of which comprises the measuring instruments by means of which it is possible to read off from a scale the actual dimension being measured, and the other, those used for accurately determining whether a dimension is accurate and equal to a certain predetermined dimension. Within the first group come the instruments already mentioned — the scale, the vernier caliper, the micrometer, and the measuring machine, as well as protractors. The second group comprises what are known as "gages" — devices made or set to a given dimension and used simply to determine whether manufactured parts are made to these dimensions. For example, a plug gage is simply a round piece of steel, accurately ground to a given size, which is used for determining whether a drilled or a bored hole is made to the dimensions required, this being determined by inserting the plug into the hole, in which it should fit accurately. A ring gage, again, is a piece of steel provided with an accurately ground hole which is used for testing the accuracy of the diameter of shafts or other cylindrical pieces of work required to be of the exact size of the gage. There are a great many other types of gages, however, that may be used for measuring work, either of cylindrical or of other shape.

Generally speaking, gages are intended to be used as fixed measuring instruments, and each gage, in general, is intended to measure but one dimension; hence, gages are used only in interchangeable manufacture, or in cases where a great number of pieces of the same dimensions would be measured by them. The section on GAGES, Vol. III, p. 268, describes the different kinds of gages used both for internal and external measurements, and for the measuring of angles and tapers. So-called "dial gages," also included under the general head of GAGES, are, strictly speaking, not gages at all, but measuring instruments which indicate on a scale the exact deviation from a standard dimension. A special class of gages are those intended for thread measurements. These are dealt with briefly in the article on gages, already mentioned, and more completely under the heading THREAD MEASURING AND TESTING, Vol. VI, p. 249. The student of shop methods will find it necessary to make a thorough study of measuring and gaging methods, in case he expects to thoroughly cover some of the most important phases of shop practice.

MACHINE TOOLS AND SHOP EQUIPMENT

IN the manufacture of various classes of machinery, tools, and mechanisms, the different parts are shaped, partly or entirely, by a metal-cutting operation. Many machine parts are given the approximate shape required either by the casting or forging process, but, in most cases, it is necessary to use some kind of metal-cutting machine in order to give the casting or forging the necessary degree of accuracy and smoothness of finish. For instance, a great many parts which enter into the construction of different types of machines must have cylindrical or flat surfaces that are practically true and which conform to given dimensions within close limits; many other operations are also necessary, such as drilling holes, cutting threads in holes and on the parts which are to be screwed into the holes, etc. The machines used for such work are known as "machine tools," the term indicating, in a general way, that some form of metal-cutting or metal-forming tool is operated and controlled partly or entirely by a machine designed for that purpose. As machine tools are used in the production of all kinds of machinery and mechanical apparatus, a knowledge of the different types in use and of their general application is essential to everyone interested in the general subject of machine construction, whether as a machinist who uses machine tools, or as a designer of the parts upon which they operate.

Machine Tools. — Most machine tools perform some metal-cutting operation, although there are exceptions in the case of machines which form parts by the application of pressure, blows, or by an abrading process which may not always be a cutting operation. (For definitions of machine tools, see Vol. IV, p. 278.) The function of any type of machine tool is, in general, to impart motion either to the cutting or forming tool on the machine or to the work, or to both the tool and work; moreover, on machine tools of the metal-cutting class, provision is made for varying the cutting speed and the amount of metal that is removed for each revolution or stroke of the machine, as the case may be.

There are many different types of machine tools which vary greatly in size, because machines of this class are used on an endless variety of parts, ranging from pins or screws that are so small that their weight is scarcely perceptible when held in the hand, to castings or forgings weighing many tons. Machine tools also vary in design for the reason that some are intended for general use and may be applied in different ways, whereas others are more special in their application and may be limited to the production of a single class of work. In studying the various types of machine tools, their different uses, and how they are applied under different conditions, it is essential to consider the kind of work each type is adapted for, what factors govern the selection of different types, what cutting tools or attachments are needed, and how different machines are adjusted and used or operated. All of the more important types of machine tools are described in the ENCYCLOPEDIA, the distinct classes being referred to in separate articles which are listed in the following pages. The exact method of procedure in using these tools for different operations will be considered later, in connection with machine shop practice. The historical development of machine tools, Vol. IV, p. 278, may prove not only interesting, but enlightening, as an introduction to this general subject.

Engine and Turret Lathes. — A great many of the parts which are used to form machines of different types are of circular cross-section, some being cylindrical, others tapering, and still others combining various other forms with the cylindrical or tapering shapes. In general, the circular parts, whether cylindrical or tapering, are finished in some form of turning machine which is so designed that the work is caused to revolve at a suitable speed while a mechanically guided cutting tool, or a succession of tools, cuts it to the required form and size. The most common form of turning machine is known as the "lathe." The ordinary "engine lathe," which is found in all machine shops, may be used for a great variety of purposes, such as turning different shapes, boring holes, cutting screw threads, etc. In the section on LATHES, Vol. IV, p. 169, the general features of an engine lathe are explained. Lathes made by different manufacturers vary more or less in their construction; an attempt has been made, however, in dealing with all types of machine tools, to select as far as possible a typical design. In many cases, important features found on machines of different makes are illustrated and their application explained. In addition to engine lathes, this section describes briefly various other types, some of which are intended for special classes of work; such special types are TURRET LATHES, Vol. VI, p. 350; and BENCH LATHES, Vol. I, p. 339, which are covered by separate articles.

Planing and Slotting Machines. — The characteristic feature of a planing machine is that it has a rectilinear or straight-line movement, instead of a rotary motion, like a lathe. The plane or flat surfaces required on many machine parts are often produced by some form of planing machine, although they may also be produced by milling or grinding machines; in fact, most of the operations on different machine parts can be performed in more than one kind of machine, and for that reason it is important for the student interested in general manufacturing methods to learn what are the particular advantages of each type of machine tool. While the planer is intended primarily for finishing flat surfaces, it may also be used for machining curved or irregular surfaces by employing special tools or attachments, or by guiding the cutting tool by hand, provided sufficient accuracy can be attained by this method. The article on PLANERS, Vol. V, p. 94, describes a typical design and explains the uses of the more important features, as well as variations in other designs. The machine tools commonly known as "shapers" are also a type of planing machine intended for comparatively light work. See Vol. V, p. 343. Slotters may also be included with tools of the planing class, as they are really vertical planing machines, and are especially adapted for cutting out slots or for finishing other surfaces which can be reached more readily by a tool which moves vertically. (See Vol. V, p. 381.)

Drilling Machines. — The assembled parts of practically all classes of machinery are held together by screws, bolts, or other threaded parts, which enter or pass through drilled holes. For drilling these holes, some kind of machine is used which serves to rotate the drill and at the same time feed it through the work. The machine may drive a single drill or several drills carried by spindles that are spaced in accordance with the location of the holes. A review of different types will be found in the article on DRILLING MACHINES, Vol. II, p. 456. While machines of this class are used principally for drilling holes, they are also employed for tapping and other operations. (See also PNEUMATIC DRILLING MACHINES, Vol. V, p. 120.)

Boring Machines. — The term "boring machine," as applied to vertical and horizontal types, indicates, to a very limited degree, the range of work for which such machines may be used. The vertical boring mill belongs to the lathe group, and may be compared to a lathe placed in a vertical position. Machines of this class are used extensively for turning operations, and frequently boring operations constitute a small part of their work. Some vertical boring machines, however, which are designed along entirely different lines, are intended principally for boring operations, or may be used exclusively on that kind of work. Horizontal boring machines may also be capable of wide application, either for drilling, boring, or milling; or they may be designed exclusively for some operation such as boring engine cylinders. Both the horizontal and vertical types are dealt with in the article on BORING MACHINES, Vol. I, p. 469.

Milling Machines. — Milling machines (Vol. IV. p. 390) of different classes represent another indispensable type of machine tool. They are especially valuable for forming irregular surfaces on duplicate parts, as well as for producing flat or plane surfaces. The milling process, or the use of a rotary cutter having a number of cutting edges which come into action successively, is applied in a great variety of ways. Some machines designed especially for milling slots, edges, etc., of special or irregular shape, are known as "profiling machines," Vol. V, p. 172. ENGRAVING MACHINES, Vol. III, p. 58, are also special types of milling machines.

Grinding Machines. — The machine tools previously referred to all utilize hardened steel cutting tools, whereas grinding machines are equipped with abrasive wheels which have innumerable cutting points that act upon the work as it is brought into contact with the rapidly revolving wheel. Grinding machines are capable of finishing hardened parts to correct any distortion resulting from the heat-treating process, and they are also applied to the grinding of many unhardened parts in connection with manufacturing, because the modern grinding machine and the high-grade wheels now available provide an efficient means of rapidly securing a smooth finish combined with remarkable accuracy. The section on GRINDING MACHINES, Vol. III, p. 432, includes the types intended for cylindrical work and also the surface grinders for flat or plane surfaces. The WORM GRINDER, Vol. VI, p. 552, and the GEAR TOOTH GRINDER, Vol. III, p. 382, are special types of machines intended for a single class of work.

Automatic Turning Machines. — Machine tools may be manipulated entirely by hand or they may be semi-automatic or completely automatic, all movements essential to the completion of a given piece being derived from some kind of mechanism forming part of the machine. One of the problems of machine shop management is to determine to what extent automatic machines are to be used. The automatic type produces parts rapidly, but its field of usefulness is somewhat restricted as compared with some of the hand-controlled machines which are designed especially for general application. The automatic machine also requires special tool equipments and a certain amount of adjustment for each particular job; whereas many of the simpler hand-operated machines are capable of using one set of tools for many different purposes. This matter of machine tool selection depends largely upon the number of duplicate parts required. This point will be more apparent after reading the section on AUTOMATIC TURNING MACHINES, Vol. I, p. 178, and comparing the machines described with the other types of turning machines previously referred to. These automatic machines are practically mechanically operated lathes, and, like the latter, they are intended primarily for turning, although they are extensively used for other operations, such as drilling, reaming, tapping, etc.

Automatic machines are excellent examples of machine design. The skillful designer knows how to arrange and use parts, each of which is simple, to produce intricate mechanical movements. That is why the student of machine design, as well as the man interested in general methods of manufacture, will find it profitable to study the details and general arrangement of automatic machines embodying ingenious ideas and principles that may be applied to other classes of machinery.

Gear-cutting Machines. — As gears of different kinds are used extensively as a means of transmitting motion, and as their efficiency depends largely upon the accuracy of the tooth shapes, gear-cutting machines include a great variety of types and embody many ingenious forms of mechanisms. An unusually complete treatise on this subject will be found in Vol. III, p. 331. The fundamental principles governing the operation of different types of gear-cutting machines are first explained and then machines operating in conformity with these principles are described. Many different types of machines have been designed for cutting the same type of gearing; and machines varying considerably in form and in the principle of their operation are required for different types of gears; hence, the great variety in design. After studying these machines and the principles governing their operation, a gear will seem more than a circular part having teeth around the edge; the man who knows how gear teeth are cut will appreciate the difficulties involved in the production of those well-formed teeth which roll in mesh with a mating gear with such remarkable smoothness of action.

Cutting-off Machines. — The long bars of stock produced in rolling mills are used in machine shops for making a great many parts required in machine construction. The procedure is to first cut off suitable lengths from a bar, and then form these shorter lengths to the required shape by some machining process in a lathe or some other machine tool. The machines used for cutting off bars of stock may be designed to rotate the bar and sever it with a cutting tool, or they may have power-driven saws operating either with a rectilinear motion or a rotary movement. These power-driven sawing machines may also be used for cutting structural material. (See CUTTING-OFF MACHINES, Vol. II, p. 290, and HACKSAW MACHINES, Vol. III, p. 493.)

Classes of Machinery for Thread Cutting. — The cutting of screw threads may be done on machines adapted to various other operations, or on machines intended especially for thread cutting. The lathe is frequently used for cutting both external threads and internal threads in holes; semi-automatic and automatic turning machines, such as turret lathes and screw machines, are also used for thread-cutting operations. Among the machines designed especially for threading operations may be mentioned bolt cutters, pipe threading machines, thread milling machines, and thread rolling machines. The method of applying machine tools in general to this kind of work are explained in different articles referred to later in this GUIDE under the heading "Machine Shop and Toolmaking Practice."

Broaching and Keyseating Machines. — The broaching process is usually applied to the finishing of holes. A tool of the right shape and having a series of teeth is drawn (or sometimes pushed) through the work which is cut to the shape corresponding to the form or contour of the cutting teeth. A broaching machine of the type used for drawing broaches through the work is described in Vol. I, p. 516. Most of the work done by broaching could be performed on some other kind of machine tool, but broaches and broaching machines make it possible to finish work for which they are adapted more rapidly and accurately than would be possible by other methods of machining.

The extensive use of keys for holding gears, pulleys, flywheels, etc., in place on their shafts has lead to the development of special machines for cutting the keyseats or keyways in the hubs of parts of the class mentioned. Work of this kind is often done on a slotting machine or shaper, but a regular keyseating machine (Vol. IV, p. 152) is usually more convenient and effective.

Machine Tool Speed and Feed Mechanisms. — In all metal-cutting operations, it is important to do the cutting as rapidly as possible, in order to operate the machine efficiently. The cutting speed is limited, however, by the fact that a tool dulls and deteriorates rapidly if the speed is excessive. For this reason, most machine tools are driven through some form of mechanism which enables the speed to be changed, as some metals can be cut at a higher rate of speed than others, and variations in the size of different parts also necessitate changes in the speed of rotation, in order to secure a given surface speed at the point where the tool is at work. The article on MACHINE TOOL DRIVES, Vol. IV, p. 270, contains general information of especial value to machine tool designers. The different forms of mechanisms used on machine tools of various classes are described in the section SPEED AND FEED MECHANISMS, Vol. V, p. 402.

The speed mechanism controls the rate of cutting, whereas the feed mechanism controls the amount of metal removed by the tool for each revolution of a machine of the revolving type, or for each stroke of a machine which operates with a rectilinear movement. The mechanisms described in this section constitute some of the most important features found on machine tools.

Lubrication of Cutting Tools. — It is common practice to flood metal-cutting tools with some cooling compound or lubricant when they are in operation, principally to cool the cutter and work and thus make it possible to operate the machine at a higher rate of speed without excessive dulling of the tool. There are various ways of supplying the lubricant to cutting tools, and of collecting it after use, so as to avoid waste and permit of again using the lubricant. Lubricating systems vary more or less with different designs of machines and types of cutting tools. Various forms of distributing pipes and nozzles, methods of recovering used lubricants, piping connections for movable slides, and drainage pan tanks and reservoirs are illustrated in the article LUBRICATING SYSTEMS FOR CUTTING TOOLS, Vol. IV, p. 256.

Shearing and Punching Machines. — In working with sheet metal or flat plates, it is often necessary to split the sheets or trim the edges to a given form. Shears operated either by hand or by power are generally used for this work. A brief review of machines of this class will be found in Vol. V, p. 354. Another operation common to sheet metal work, especially on fairly heavy plates, is that of punching holes, which usually are to receive rivets. While such holes could be drilled by means of a drilling machine, they can be punched more rapidly, the punch and its die being practically a small circular shear that forms the hole. Tools of this class are described in Vol. V, p. 214.

Power Presses for Die Work. — Dies of various kinds are used extensively for forming parts from sheet metal, especially if the shape is irregular and many duplicate parts are required in connection with manufacturing work. Dies are also employed for perforating, embossing, drawing seamless shells, and for innumerable other operations. The power-driven presses to which the dies are attached vary greatly in design and size; their purpose is to supply the necessary motion and pressure for forming the work in the die. Presses, in general, are so constructed that the depression of a foot-treadle starts the press and an automatic clutch stops it after completing a working stroke, unless arranged for continuous operation. The section on POWER PRESSES, Vol. V, p. 149, explains the more important constructional features and includes information on the application of different types of presses. The special designs of clutches used for power presses are described in the section on CLUTCHES, Vol. II, p. 137.

Machine Tool Accessories. — Machine tools, such as lathes, planers, drilling machines, milling machines, grinding machines, etc., require some auxiliary equipment before they can be used. The number of special tools or accessories varies with different machines and also with different operations. In addition to the cutting tools needed, special provision must be made, at times, for supporting or holding the work, while the cutting tools are in operation. Some tools of this class are known as "arbors" or "mandrels," different types and their applications being shown in the article on ARBORS AND MANDRELS, Vol. I, p. 110. Some arbors are used for holding a cutting tool instead of the work. (See Vol. I, p. 123.) The various kinds of chucks used on machine tools represent another important accessory. Some chucks are intended for holding parts while they are being operated upon and others for holding cutting tools. (See CHUCKS, Vol. II, p. 110; MAGNETIC CHUCKS, Vol. IV, p. 290; DRILL CHUCKS, Vol. II, p. 429.) In order to transmit motion from the rotating member of a machine to the work, "dogs" or "drivers" are frequently used, especially in connection with lathe work. (See Vol. II, p. 394.) When rather slender shafts or other parts are being turned between the centers of the lathe, it is often necessary to support them, and steadyrests are used for this purpose. (See Vol. V, p. 552.) Steadyrests are also needed in connection with most cylindrical grinding operations. (See Vol. V, p. 545.) The cutting tools used on machines adapted for general operations may be either forged solid or consist of a toolholder in which a cutter is inserted. (See TOOL-HOLDERS, TURNING, Vol. VI, p. 297, and THREAD-TOOL HOLDERS, Vol. VI, p. 278.) In addition to the auxiliary tools referred to, many special types are needed for different classes of work. A variety of these tools and attachments are shown in the illustrations of operations described in articles referred to in this GUIDE under "Machine Shop and Toolmaking Practice."

Special Attachments for Machine Tools. — The range of work that can be done on some machine tools can be extended considerably by equipping the machine with a special attachment. The dividing or indexing head is an attachment for the milling machine to permit dividing circular parts into an equal number of spaces, or for imparting a rotary motion to the work for the purpose of milling a helical groove. (See INDEXING, Vol. IV, p. 47.) Attachments are also used on the milling machine to convert it temporarily into another type, or to permit operations for which the milling machine was not primarily designed, as explained in the article on MILLING MACHINE ATTACHMENTS, Vol. IV, p. 386. Engine lathes often have an attachment for taper turning, described in Vol. VI, p. 183, and the lathes used for toolmaking operations have attachments for giving the tool a reciprocating motion for backing off the teeth of milling cutters. (See RELIEVING ATTACHMENTS, Vol. V, p. 258.) Planers have, as a rule, much less auxiliary equipment than lathes, although they are sometimes supplied with attachments intended to increase the range of work that can be done on an ordinary machine. Different types are described in the article on PLANER ATTACHMENTS, Vol. V, p. 91.

Gaging and Testing Appliances. — While the high-grade machine tools now manufactured are capable of extremely accurate results, it is necessary to use various forms of gages in order to insure the making of finished parts to specified sizes and the production of duplicate parts uniform in size. Some of these tools are adjustable and graduated to show linear or angular measurements; others are not adjustable, but intended for testing the size of some part which is made repeatedly. The ordinary forms of measuring and gaging instruments and tools are referred to in this GUIDE under the general heading "Standards and Methods of Measurement." In addition to the tools of this class, there are other forms used in machine shops and tool-rooms for detecting inaccuracies either in regard to the location or form of flat or curved surfaces. Representative tools of this class are described in the following articles: SURFACE GAGE, Vol. VI, p. 127; INDICATORS, CENTER AND TEST, Vol. IV, p. 55; SQUARES, Vol. V, p. 520; STRAIGHTEDGES, Vol. VI, p. 94; SURFACE PLATE, Vol. VI, p. 128; and LEVELS, Vol. IV, p. 198.

Tools Used in Assembling. — When parts that have been finished in machines of different classes are assembled to form a complete machine or mechanism, some fitting by hand may be necessary, such as chipping or filing. At the present time, however, such work is avoided, as far as possible, and is usually unnecessary, because machine tools now available are capable of producing parts so accurately that they may be assembled without difficulty. Hand work, however, is often necessary, there being various reasons why it is not practicable to eliminate it entirely. The tools used most frequently for fitting by hand are hand-hammers, Vol. III, p. 498; chisels, Vol. II, p. 107; and files. As files are made in a variety of forms, information is given (Vol. III, p. 117) on their classification and the different purposes for which the various types are intended. Owing to the extensive use of files, articles are included on FILE MANUFACTURE, Vol. III, p. 110, and FILE TESTING, Vol. III, p. 123. The equipment referred to in the following articles is also of especial value in connection with fitting and assembling: VISES, Vol. VI, p. 438; BENCHES, Vol. I, p. 339; OILSTONES, Vol. IV, p. 504; WRENCHES, Vol. VI, p. 552; and RATCHET DRILLS, Vol. V, p. 231.

Abrasives and Grinding Wheels. — Abrasive materials, such as are used in machine shops and tool-rooms, may be in the form of grinding wheels, in loose granular form, or applied to the surface of paper or cloth. Grinding wheels are extensively used both for grinding or sharpening edged tools and for finishing machine parts, usually after the approximate size and shape required are obtained by a preliminary machining operation, such as turning, planing, or milling. Loose abrasive may be used for correcting slight errors between surfaces, either by a grinding-in or lapping process, and they are also employed for polishing operations. Abrasive paper and cloth is extensively used for polishing, and, in the form of belts or disks given motion by a suitable machine, for grinding and finishing different materials. Some commercial abrasives are obtained from natural sources, but most of them are produced artificially. (See ABRASIVES, Vol. I, p. 3; and ABRASIVE PAPER AND CLOTH, Vol. I, p. 2.)

The formation of loose abrasive into grinding wheels capable of withstanding the high speeds essential to efficient grinding involves some process which serves to bind the grains of abrasive firmly together. Different bonding processes are described in the section on GRINDING WHEELS, Vol. III, p. 471, which also explains the different methods of grading wheels, the classes of work for which different types of wheels are adapted, methods of mounting grinding wheels, the speeds at which they should be operated, methods of truing wheels, and the prevention of accidents. The article on GRINDSTONES, Vol. III, p. 487, and EXHAUST SYSTEMS FOR GRINDING AND POLISHING WHEELS, Vol. III, p. 75, should also be referred to.

Hoisting and Conveying Apparatus. — In shops building heavy machinery, hoists and cranes are needed to lift heavy castings and forgings, or for conveying them from one machine to another, as well as to assist in the work of assembling heavy parts. These hoists are operated either manually or by power. If power-driven, compressed air or electricity is generally employed. The article on HOISTS, Vol. IV, p. 26, covers types of apparatus that are used principally for the lighter classes of work. General information on more powerful hoisting appliances is given in the article on CRANE DESIGN, Vol. II, p. 232. The usual method of connecting the hook of an ordinary crane or hoist to the object to be lifted is by means of a chain or rope (see CHAINS AND SLINGS FOR HOISTING, Vol. II, p. 56), but many forms of hoisting apparatus are now equipped with lifting magnets. These magnets grip the parts to be lifted as soon as they come into contact with them, no chains or rope slings being required. The different types of lifting magnets are described and general information on their design is given in the article on LIFTING MAGNETS, Vol. IV, p. 203.

CONVEYORS, Vol. II, p. 199, are not used very generally in machine shops, but they are indispensable for handling coal, ore, and many other materials which must be loaded, unloaded, or transported in the operation of power plants, blast furnaces, or manufacturing plants.

MACHINE SHOP AND TOOLMAKING PRACTICE

THE practice followed in machine shops in cutting and finishing castings and forgings, or in producing parts from bars of stock, and assembling different parts to form machines of various classes, depends largely upon the nature of the work, its size and shape, the degree of accuracy required, and the number of duplicate parts needed. In general, machine shop work involves, first, the selection of a tool or machine; second, the adjustment or operation of that tool or machine so that it performs the necessary work; and, third, the assembling of separate parts so that they conform to the plan or design of the machine or mechanical device being constructed. Most parts which are partly or entirely produced by some machining process can be operated upon in more than one type or design of machine tool, so that the question of tool selection involves a knowledge of the particular kinds of work for which different machines are especially adapted. This point may be illustrated by considering the method of making a small screw. Work of this kind could be done in an ordinary engine lathe, and, if one or only a few screws were needed, such a machine would probably be superior to any other; but, if a great many screws were required, an automatic screw machine would be much superior to the lathe, as it is intended especially for such work. Similar comparisons might also be made in the case of different types of planing, milling, or grinding machines, as well as of other classes of machine tools.

Methods of Studying Shop Practice. — The adjustment and operation of different machine tools depends largely upon the type of the machine and the exact nature of the operation. Men not experienced in such work should study the exact methods of procedure in performing various operations. A great deal of work connected with machine construction depends almost entirely upon direct *knowledge*, rather than upon skillful manipulation of tools; that is the reason why good treatises on different branches of shop practice are of such practical value. Some shop men contend that it is necessary to learn everything by actual experience; that is a good way to learn, but it has one great disadvantage; namely, that the average man's experience, especially at the present time, does not cover enough mechanical territory. Frequently, men who rely entirely upon personal experience possess a mechanical knowledge that is bounded by the walls of the shop in which they work. MACHINERY'S ENCYCLOPEDIA contains more definite information, capable of practical application, than any man could acquire in a lifetime of actual experience.

Shop Practice for Designers. — It should not be inferred that the articles on different branches of machine shop practice are of value only to those actually engaged in shop work, because they may also be studied with the greatest profit by draftsmen or machine designers. Some designers consider very carefully the intended use and strength of a machine part, but do not realize the importance of designing it in such a manner that economical manufacturing methods are possible. This is especially true of young technical graduates and others of limited experience; they often design parts that meet all requirements as to strength and effectiveness in performing the service required, but, frequently, these parts are considered to be of very inferior design by the shop foreman. The trouble often is that the designer did not consider, except in a general way, how the casting or forging should be machined to enable the work to be done efficiently. While designers, naturally, think of finished surfaces, bearings, drilled and tapped holes, recesses, etc., there are many who do not consider the matter from the viewpoint of economical production, nor the exact methods and tools which must be employed in performing the various operations.

The analysis of manufacturing problems encountered in machine design is something like this: Can the part be machined? How? On what type of machine? Would a simple change make it possible to use another machine to better advantage? Can various members be assembled without difficulty? When it is decided that the work can be machined on some of the standard machine tools, many designers do not consider it necessary to go into the subject further, unless they have had practical experience in tool designing and manufacturing; but there are many important points in connection with machine designing that materially affect the cost of manufacture, such as the location of holes that must be drilled and tapped, the general shape of castings or forgings, whether projecting lugs should be a part of a casting or be attached to it, the use of temporary flanges or lugs for holding or driving a part while machining it, the coring of internal grooves or recesses to avoid machining operations, etc. Of course, the effectiveness of a piece of mechanism must be the first consideration, and the weight, strength, and even the general appearance are important features that must be considered; in fact, the methods of manufacture may, in some instances, be secondary, but, nevertheless, it is essential to study them carefully. The ENCYCLOPEDIA contains a great deal of information covering general practice and methods of procedure which will assist the designer to choose economical methods of production.

Application of Engine and Turret Lathes. — The engine lathe is the most common of all machine tools. This type of machine may be used for turning cylindrical or tapering parts, for boring holes, for facing flat radial surfaces, for cutting screw threads, and for numerous other operations. The arranging of a lathe for any operation usually involves selecting a cutting tool of the right shape and adjusting the machine to feed the tool at the proper rate, unless the cuts are very short and the movements of the tool are controlled entirely by hand manipulation. Provision must also be made for supporting the work. That part of the section on lathes following the paragraph headed *Application of Engine Lathe*, Vol. IV, p. 180, covers the more elementary features of lathe operation. The following articles should also be studied: CENTERING, Vol. II, p. 38; LATHE CENTERS, TRUING, Vol. IV, p. 169; TAPER TURNING, Vol. VI, p. 181; SHAFT TURNING, Vol. V, p. 341; and KNURLING, Vol. IV, p. 155. The grinding of the cutting tools used in lathes and other types of machine tools is very important, and it is advisable for the student to understand the principles of tool grinding before proceeding farther. (See TOOL GRINDING, Vol. VI, p. 293.) The turret lathe is a development of the engine lathe and is intended more for manufacturing duplicate parts than for general application, although machines of this kind are capable of a wide range of work, when equipped with the necessary tools. The general application of turret lathes is dealt with in Vol. VI, p. 350.

Operation of Planers, Shapers, and Slotters. — Before the planing machine was invented, flat or plane surfaces were finished by chipping with a hammer and cold-chisel and then filing the rough surface to make it smooth. Much of this work is now done on some form of planing machine. A general idea of planing practice may be obtained from the article PLANING METHODS, Vol. V, p. 110. The causes of distortion resulting from improper methods of clamping parts to the work table of a planer are explained in Vol. II, p. 122. As shapers operate on the same general principle as planers, the article on SHAPERS, Vol. V, p. 343, deals more especially with the constructional features common to different types of shapers. The cutting tools used on shapers are also similar to planer tools, although they are usually much smaller, since shapers are intended for a lighter class of work than planers. The slotting machine, which is practically a vertical planer, is often equipped with end-cutting tools and is adapted to both straight and circular planing operations, as explained in the article on SLOTTING MACHINES, Vol. V, p. 382.

Operation of Milling Machines. — The milling process is extensively applied not only to manufacturing, but also in connection with many operations on tools, dies, etc. It is especially adapted to the forming of duplicate parts that are not symmetrical but irregular in shape, as well as for finishing flat surfaces, cutting grooves or slots, milling helical or spiral grooves, and for many other purposes. The most fundamental milling processes are described in Vol. IV, p. 400. Milling machines are often used for cutting the teeth in gears, especially if only a few gears are needed (Vol. III, p. 322), for fluting reamers and taps, and for other operations that require a circular part to be divided into equal spaces or divisions. The special attachment used for obtaining uniform spacing is known as a "dividing" or "indexing head;" it is sometimes called a "spiral head," because it is also used for milling spiral or helical grooves. The different methods of spacing or indexing work are described in an article on INDEXING, Vol. IV, p. 47, which includes the simple, compound, and differential systems.

There are two general methods of producing irregular forms, in duplicate, by milling; one is by using a formed milling cutter (Vol. IV, p. 380), having cutting edges shaped to give the work the required form, and the other is by employing a special model or templet that serves to guide the milling cutter. The latter principle is used in milling irregular profiles (see PROFILING, Vol. V, p. 172), in milling cams (see CAM MILLING, Vol. I, p. 551), and for engraving dies, letters, or designs (see ENGRAVING MACHINES, Vol. III. p. 58).

General Drilling Practice. — Drilling a hole in a piece of iron or steel is a very simple operation, but general drilling practice as carried on in large machine shops is a more profound subject than many suppose. As a great number of holes must be drilled in many machine-building plants, the problem is how to do the work most efficiently. The machine should be of a type and size adapted to the work, and special equipment in the form of drill jigs for locating and guiding the drills is universally used for drilling duplicate parts. The drilling of exceptionally deep holes also necessitates special tools and methods. The article on DRILLING, Vol. II, p. 437, covers the general application of drilling machines. In view of the fact that efficient results cannot be obtained unless drills are correctly ground, the fundamental principles of drill grinding (Vol. II, p. 432) should be thoroughly understood. (See also DEEP-HOLE DRILLING, Vol. II, p. 446, and DRILLING MACHINES, Vol. II, p. 456.) The article on JIGS AND FIXTURES, Vol. IV, pp. 114 to 120, inclusive, should also be referred to, as it contains general information on the application of jigs to drilling.

Application of Grinding Machines. — When parts are to be ground either to correct distortion, resulting from a heat-treatment process, or as an efficient means of finishing surfaces smoothly and accurately to a given size, the type of machine to use and the method of procedure are governed by the form of the work, its size, the degree of accuracy necessary, and the amount of grinding to be done. The article on GRINDING METHODS, Vol. III, p. 445, is a condensed treatise on this subject. One of the important requirements for any grinding operation is to use a wheel that is suitable for the work at hand. The principles governing grinding wheel selection are explained in Vol. III, p. 484. The efficiency of grinding operations, in general, also depends largely upon the relative speed of the wheel and work, as explained in the article on GRINDING SPEEDS, Vol. III, p. 468. The following articles should also be studied: STEADYREST FOR GRINDING, Vol. V, p. 545; DISK GRINDING, Vol. II, p. 383; CYLINDER GRINDING, Vol. II, p. 295; CRANK-

SHAFT GRINDING, Vol. II, p. 265; CAM GRINDING, Vol. I, p. 548; PULLEYS, FORM GRINDING, Vol. V, p. 180; GEAR TOOTH GRINDING, Vol. III, p. 382; and ROLL GRINDING, Vol. V, p. 278. For descriptions of different types of grinding machines, see Vol. III, p. 432.

Horizontal and Vertical Boring Machines. — When castings or other parts are quite large in diameter in proportion to their length or height, the vertical boring mill is frequently used for turning and boring operations. A flywheel is a good example of work for which the vertical boring mill is adapted. The article on BORING MACHINES, Vol. I, p. 469, includes, in addition to a general description of a typical machine, information on the practical application of boring mills in general. The horizontal type of boring machine is intended for an entirely different class of work, as explained in the same article.

Adjustment and Use of Automatic Turning Machines. — At the present time, almost any cylindrical machine part of small or medium size can be made in some form of automatic turning machine, which is one reason why there are many problems to solve in setting up, adjusting, and operating machines of this class. The variety of work that can be done on a modern automatic screw machine is endless, and the production of each different part requires careful planning. Tools must be selected that will give accurate and efficient results, and these tools must be properly applied. The successive order of the different operations is a factor upon which the rate of production largely depends. The problem is often still further complicated by the fact that some of the parts can be produced in several different ways, but usually there is a good reason why one way is preferable. Many of the more important tools used on "automatics" and the operations for which they are intended are dealt with in the article AUTOMATIC SCREW MACHINE TOOLS AND OPERATIONS, Vol. I, p. 150. This article is intended to supplement the one on AUTOMATIC TURNING MACHINES, Vol. I, p. 178.

Methods of Cutting Threads. — The methods of cutting screw threads range from the use of a tap or die that is turned by hand, to a special machine driven by power and designed exclusively for threading operations. Threads are frequently cut in the engine lathe, which must then be equipped with gearing for producing threads of different pitch. The article on THREAD CUTTING, Vol. VI, p. 234, explains how to determine, by calculation, the gears to use for any pitch, and includes a great deal of general information on thread-cutting methods. In connection with this subject, the following articles should be studied: THREADS, Vol. VI, p. 264; THREAD TOOLS, Vol. VI, p. 281; THREAD MILLING, Vol. VI, p. 258; THREAD ROLLING, Vol. VI, p. 261; and THREAD MEASURING AND TESTING, Vol. VI, p. 249.

In building certain classes of machinery, a great many holes must be threaded to receive stud-bolts, cap-screws, machine screws, etc., and threading operations of this kind are done by means of taps. The general methods of tapping and the equipment used for this work are described in the article on TAPPING, Vol. VI, p. 194. The special machines used for cutting the threads on bolts of various kinds are known as "bolt cutters." (See Vol. I, p. 449.) Special machines are also used for threading the ends of pipes where there is enough work of this kind to warrant using a power-driven machine instead of a die that is turned by hand. (See Vol. V, p. 55.)

Special Turning and Boring Tools. — In the past, machine tools that were comparatively simple and intended principally for general work were used, but now many of the machines employed in manufacturing are complex and, in some cases, actually built around the parts they produce. The small auxiliary tools and attachments used in the modern machine tools, however, are not lacking either in cleverness of design or in effectiveness as a means of enabling duplicate parts to be produced accurately and rapidly. In many cases, a special tool greatly increases the range of a machine, or enables it to perform work which otherwise could not be done in it. A variety of these special designs are described in the following articles, which also include many tools adapted for general work: BORING AND RECESSING TOOLS, Vol. I, p. 457; ECCENTRIC TURNING, Vol. II, p. 520; SPHERICAL TURNING, Vol. V, p. 444; ELLIPTIC TURNING AND BORING, Vol. III, p. 54.

Cutting the Teeth of Gears. — One of the practical problems frequently encountered in building various kinds of machinery is that related to the cutting of gear teeth. While most gears are cut in machines designed especially for this purpose, the milling machine is quite generally used for gear cutting, especially if few gears are needed. The general procedure in cutting spur, spiral, helical, and worm gearing is explained in the article on GEAR CUTTING IN MILLING MACHINE, Vol. III, p. 322. After the cutting of gears in the milling machine is thoroughly understood, the application of regular gear-cutting machines (see Vol. III, p. 331) may be more readily comprehended, although many of these latter machines operate on an entirely different principle from the ordinary milling machine. In connection with this subject, reference should be made to the article on RACK CUTTING, Vol. V, p. 227; GEAR TOOTH CHAMFERING, Vol. III, p. 381; and GEAR TOOTH GRINDING, Vol. III, p. 382. Specific information on the forms of cutters used on certain types of gear-cutting machines will be found in the following articles: GEAR-CUTTERS, Vol. III, p. 320; HOBS FOR SPUR AND SPIRAL GEARS, Vol. IV, p. 13; and HOBS FOR WORM-GEARS, Vol. IV, p. 22. As gear-cutting methods are closely related to the principles of gear design, the articles dealing more especially with the design of gearing should be carefully studied. (See SPUR GEARING, Vol. V, p. 501; BEVEL GEARING, Vol. I, p. 352; WORM GEARING, Vol. VI, p. 541; SPIRAL GEARING, Vol. V, p. 461; and HERRINGBONE GEARS, Vol. III, p. 544.)

Speeds and Feeds for Metal Cutting. — Ordinarily, in starting any metal-cutting operation on a machine tool, the first step, after the machine is properly adjusted and the work is in position, is to regulate the speed or rate at which the cutting is done. On many machines this involves adjusting either the rotary speed or the rectilinear motion of the tool or work, and regulating the amount of metal that is removed by the tool for each stroke or revolution of the machine. For instance, a lathe should revolve the work as rapidly as possible without excessively wearing the cutting tool, and the tool should feed a certain amount for each revolution of the part being turned. The numerous factors governing the selection of speeds and feeds of different machine tools are considered in the section on SPEEDS AND FEEDS, Vol. V, p. 433. This section also contains a great deal of data obtained from actual practice which may be used as a general guide, or until actual experience demonstrates what speeds and feeds give the best results for any particular class of work. As the speed of cutting depends partly upon the use of lubricants, this subject should also be considered, as explained in LUBRICANTS FOR MACHINING OPERATIONS, Vol. IV, p. 253.

Limits and Allowances for Fitting. — In view of the fact that some machine parts must fit tightly together, whereas others must be free to slide or revolve relative to each other, it is apparent that there must be some basis for determining the degree of tightness or looseness, as the case may be; moreover, as it is not practicable to finish any part exactly to a given size with any assurance that the dimension is absolutely correct, and since unnecessary accuracy means a waste of time, it is the general practice, especially in connection with the manufacture of duplicate parts and machines, to specify certain limits representing the maximum and minimum sizes, or the tolerance permitted, to avoid unnecessary refinement. These fit allowances and limits or tolerances vary considerably for different classes of work, and are usually given on drawings and are specified by the designer. (See FIT ALLOWANCES FOR MACHINE PARTS, Vol. III, p. 144; and LIMIT, Vol. IV, p. 210.)

Laying Out Machine Parts. — Lines are often drawn on parts that are to be machined, in order to show approximately, at least, the location of finished surfaces and frequently to prevent removing so much metal from one side of a casting or forging that there is not enough metal on some other side to permit finishing it. The drawing of such lines is known as "laying out," and while it is important for the machinist or toolmaker to know something about the general procedure in laying out machine parts, such work is done very little at the present time, owing to the extensive use of jigs and fixtures which hold parts in the correct position for machining them, and guide the cutting tools so that lines indicating finished surfaces or the location of holes are unnecessary. In many repair shops, however, and other places where a great variety of work is handled, it is not economical to make jigs or fixtures for many operations, and it is necessary to lay out the parts. (See LAYING OUT MACHINE PARTS, Vol. IV, p. 188; and LAYING OUT ANGLES, Vol. I, p. 94.) The article on SHEET METAL PATTERN DRAFTING, Vol. V, p. 356, also contains information of practical value in connection with this work.

Assembling Machine Parts. — The work of assembling the parts that form a machine may involve little more than arranging these parts in the right relation to one another and applying and tightening the screws, nuts, bolts, or other fastening devices that are used to hold them together. In many cases, however, the work of assembling and erecting involves more or less fitting and trimming, either by chipping, filing, or scraping. Tests for alignment between different parts may also be necessary, and there are many other kinds of work done in assembling departments. The article on ASSEMBLING MACHINE PARTS, Vol. I, p. 128, explains the general requirements connected with this work and contains examples from practice illustrating different methods of procedure and the use of special equipment designed to facilitate assembling operations. The following kindred subjects should also be studied: CHISELS, Vol. II, p. 107; FILING, Vol. III, p. 128; SCRAPING MACHINE PARTS, Vol. V, p. 319; BABBITTING BEARINGS, Vol. I, p. 199; VALVE GRINDING, Vol. VI, p. 382; SHAFTING ALIGNING, Vol. V, p. 336; and BALANCING, Vol. I, p. 205.

Locomotive Repair Work. — The general repair of locomotives includes a variety of work that is instructive along practical lines, and for that reason the more important branches of locomotive repair work are dealt with in a special section of the ENCYCLOPEDIA. This article is not intended exclusively for men in railway shops, but for everyone interested in general machine shop practice. (See Vol. IV, p. 224.)

Wire Forming and Spring Winding. — A piece of wire with some bends and twists in it is not especially interesting unless we know something about the methods of forming wire parts — then a small piece of bent wire *is* interesting, because it suggests to the mind the tool or machine used in changing it from the straight form to what may be an accurate and symmetrical shape. Bent wire parts are now used for many different purposes, and ingenious machines and tools are frequently employed in forming them. The article on WIRE FORMING, Vol. VI, p. 515, covers the general conditions involved in wire forming, the operation of wire forming machines and wire straightening devices, and other general information. Different methods of winding springs are also described in the article SPRING COILING, Vol. V, p. 480.

General Toolmaking Practice. — The construction of machinery and tools is fascinating work to the man with a natural bent for mechanics, because there is an almost endless variety of problems, especially in the making of various classes of tools. If a part requiring several operations is to be machined, it is necessary to decide how and where to begin, and how to proceed so that the different operations follow in their natural order. At times, there are several ways of doing the same job; in fact, this is frequently the case, but to determine the best way often is a problem the solution of which requires an intimate knowledge of the use of various tools and the application of approved methods. Much of the work done by toolmakers must be so accurate that the ordinary methods employed in machine manufacture are not suitable. Drilling a few holes through a plate may seem like a simple operation, but if these holes must be located certain distances apart and be of a given diameter, within a fractional part of a thousandth of an inch, the operation may prove very difficult, unless the toolmaker follows a method that will insure the required degree of accuracy. The work of the toolmaker requires, as a rule, considerable skill in the handling of tools, owing to the delicate and accurate nature of many toolmaking operations. While such skill must be acquired by experience and practice, a general knowledge of many of the fundamental methods and processes employed in tool work may be obtained from the treatises listed herewith: LOCATING METHODS, Vol. IV, p. 211; DIVIDING METHODS, Vol. II, p. 387; SINE-BAR, Vol. V, p. 366; CUTTER GRINDING, Vol. II, p. 285; LAPS AND LAPPING, Vol. IV, p. 158; and SEASONING STEEL AND CAST IRON, Vol. V, p. 330. Much practical information may also be obtained from the articles on tool design, especially those which follow: DRILLS, Vol. II, p. 465; COUNTERBORES, Vol. II, p. 223; TAPS, Vol. VI, p. 203; REAMERS, Vol. V, p. 240; DIES, THREADING, Vol. II, p. 377; CHASERS, Vol. II, p. 81; MILLING CUTTERS, Vol. IV, p. 367; JIG BUSHINGS (*Methods of Making Jig Bushings*), Vol. IV, p. 98; and GRADUATING, Vol. III, p. 419. As trigonometry is of especial value in toolmaking, this branch of mathematics should be thoroughly understood. (See TRIGONOMETRY, Vol. VI, p. 324.)

Construction of Sheet Metal Dies. — The making of dies or tools of the class used principally for forming and punching sheet metal parts is a trade requiring considerable judgment, experience, and skill. The diemaker encounters a great variety of work, owing to the numerous types of dies in use and the variations in their form, and should be familiar with the use of different machine tools, such as the lathe, shaper, and milling machine. Special tools and attachments are also used for some diemaking operations. The diemaker should also understand the principles of die construction and the general application of different types of dies.

A broad general knowledge of die construction may be obtained by studying various designs and becoming familiar with those features which have proved successful in actual practice. A review of various classes of dies will be found in Vol. II, p. 363. More complete information on the most important types of dies may be obtained from the following articles: DRAWING DIES, Vol. II, p. 404; BENDING DIES, Vol. I, p. 344; SUB-PRESS DIES, Vol. VI, p. 114; PERFORATING DIES, Vol. V, p. 4; CURLING AND WIRING DIES, Vol. II, p. 282; and STAMPING OR LETTERING DIES, Vol. V, p. 523. The article on DIEMAKING, Vol. II, p. 342, deals especially with blanking dies, as dies of this type are used more extensively than any other. (See also DIE HARDENING, Vol. II, p. 340; STOP-PINS FOR DIES, Vol. VI, p. 79; and DIE-BEDS OR BOLSTERS, Vol. II, p. 312.)

Spinning Metals. — When sheet metal is used in the manufacture of various parts of circular cross-section, such as hollow cup-shaped articles, dies may be used, or the flat stock may be given the required shape by pressing it over a revolving form or model by hand-manipulated tools; the latter process is known as "metal spinning." Much more time is required to form a part by spinning than by the use of a die, but the first cost of the special equipment needed for spinning is relatively low, and, if only a few articles are needed, they are generally formed by spinning. While this process is not connected with die design or construction, it should be understood by everyone interested in methods of manufacturing sheet metal parts. The article on SPINNING METALS, Vol. V, p. 453, covers the types of tools used for this work and explains how they are manipulated in spinning different shapes that are representative of the metal spinners' art.

METHODS OF JOINING METALS

METALS in the form of flat sheets, bars, or tubes may be joined together in several ways, each having peculiar advantages. The methods adopted vary with different metals and also depend upon the size and form of the work and whether or not a tight and permanent joint is required. If two parts are to be joined so as to be readily separated, either screws, bolts, or some form of threaded joint would ordinarily be employed, but if the joint is to be permanent, the ends would usually be held together either by riveting, seaming, or by some welding or soldering process. Some methods of forming joints are intended principally to give strength enough to withstand stresses and prevent one section of the joint from separating from the other; with some other methods, the first consideration is the making of a tight joint, so that liquids or gases cannot escape through it. Metals may also be joined so that the place where they are united is not only leak-proof, but also capable of withstanding practically the same stresses as any other section. In studying this general subject, it is essential to note the classes of work to which the different methods and processes are applied, as well as the exact way in which the joint is made.

Riveting and Seaming. — The joining of plates by overlapping the ends and inserting closely spaced rivets is extensively applied in the making of boilers, steel tanks, large steel pipes, and similar classes of work. The headless end of each rivet is usually beaten over while hot to form another head and to draw the two sections of the joint tightly together, although many rivets, especially of the smaller sizes, are headed while cold. The riveting over, or the forming of the rivet head, may be done either by means of a hand hammer, by a pneumatic hammer, by the application of hydrostatic pressure, or by a pressure-rolling or spinning process. The article on RIVETS AND RIVETED JOINTS, Vol. V, p. 268, shows different methods of applying rivets and contains information and formulas of value to designers. The machines used for riveting where considerable work of this kind is done are described in the article on RIVETING MACHINES, Vol. V, p. 265. The calking of riveted joints to prevent the leakage of liquids or gases under pressure is described in a special article in Vol. I, p. 528. The ends or edges of thin sheet metals are often joined by some form of interlocking seams, especially in the manufacture of tinware and similar products, as explained in Vol. V, p. 329.

Soldering and Brazing. — The soldering process, or the melting of an alloy along the edges of the parts to be joined, after applying a suitable flux, is a rather simple operation when ordinary "soft solder" is used, and the principal object is merely that of making a tight joint. When greater strength than that obtained with soft solder, and also a tight joint is necessary, the operation usually requires considerably more experience and skill. The section on SOLDERING, Vol. V, p. 389, covers oreinary soldering methods, the fluxes and soldering fluids commonly used, the soldering of aluminum, and the electric soldering process. The use of "hard solder" for obtaining an exceptionally strong joint is generally known as "brazing." A separate article covering different brazing methods will be found in Vol. I, p. 500. (See also SWEATING, Vol. VI, p. 139; and SOLDER, Vol. V, p. 386.)

Welding Processes. — The welding of metals requires the application of heat sufficient to make the ends or edges to be joined soft and plastic enough to join either directly with each other or with some other metal that is also heated and placed between the sections to be welded. The work may be heated for welding by a forge fire, by a gas flame, or by means of electricity. When the heating is done in a forge fire, a flux is applied to the heated surfaces to protect them from oxidation and to aid in dissolving any oxide that may have formed; the hot plastic ends are united either by hammering or by the application of pressure. When a high-temperature gas flame is employed, hammering or the application of pressure is dispensed with. This method is generally known as "autogenous" welding, to distinguish it from the ordinary welding operations. When electricity is used to heat the parts to be welded, the operation may be one of fusion without pressure, or a machine may be used which forces the sections to be welded firmly together. The autogenous process and also the different electric welding processes represent very important developments which have not only revolutionized welding practice, but made it possible to unite many parts by welding which formerly were riveted or joined in some other way less satisfactory than by means of a welded joint. General information on the various welding processes will be found in the following articles: WELDING, Vol. VI, p. 468; WELDING, AUTOGENOUS, Vol. VI, p. 472; LEAD BURNING, Vol. IV, p. 195; WELDING, ELECTRIC, Vol. VI, p. 483; and WELDING WITH THERMIT, Vol. VI, p. 502. In connection with autogenous welding, see also ACETYLENE, Vol. I, p. 18; OXYGEN, Vol. IV, p. 509; and CALCIUM CARBIDE, Vol. I, p. 526.

Cementing Materials. — Adhesive substances, such as glue and cementing materials, are of little value in joining metals, although many cements are useful for sealing joints which are held together by bolts or by some form of threaded connection. The article on CEMENTING MATERIALS, Vol. II, p. 36, includes waterproof compositions, acid-proof and oilproof cements, and cementing materials possessing various properties adapted to different purposes.

FINISHING AND PROTECTING METAL SURFACES

THE finishing of metal surfaces by polishing or the covering of such surfaces with a thin coating of some other metal, may be done merely to improve the appearance of the work, or because a certain finish is essential to the usefulness of the product, making it more effective and durable. The bearing surfaces of a shaft or other revolving part are finished smoothly for the reason that rough surfaces would cut the bearings and cause excessive friction. It is also common practice to polish the surfaces of machine parts and various other products simply for the ornamental effect. What might be defined as the natural finish obtained by a polishing operation is often changed by some chemical or heat-treatment process in order to improve it or make it more durable. The plating process makes it possible to give some metals, such as iron or brass, the appearance of more expensive metals, such as nickel, silver, or gold. In engineering work, the most important processes of coating metal parts are those which are employed to protect the manufactured product from corrosion.

Present Tendencies in Practice. — The practice of polishing machine parts simply to improve the appearance, which was followed quite generally at one time, has been abandoned by many manufacturers. A certain amount of ornamental polishing, however, is advisable in the manufacture of many classes of tools and machines, for even though the finished surface may not improve the quality of the product or its practical usefulness, a nicely polished surface does, in many cases, increase the appearance out of all proportion to the cost of the polishing operation. This is also true of plating processes as applied to many manufactured articles. For information on the general subject of finishing metal surfaces, see Vol. III, p. 134.

Polishing and Burnishing. — The polishing of metal surfaces to make them smooth and bright in appearance is usually done by bringing the surface into contact with some form of rapidly revolving polishing wheel, although the part to be polished is sometimes given a rotary motion, especially when the polishing operation is done immediately after turning in a lathe. The polishing material has a slight abrading effect upon the surface of the work, and, by using suitable materials selected with reference to the nature of the work, a mirror-like finish may be obtained on steel, brass, and various other metals. Different polishing materials and processes are described in the article on POLISHING, Vol. V, p. 123. Many classes of work are given a smooth finish either by "tumbling" the part in contact with polished steel balls, or by passing the smooth point of a burnishing tool over the surface requiring a smooth finish. (See BURNISHING METALS, Vol. I, p. 521.)

Coloring Metals. — The art of coloring metals is very old. Excellent examples of this work have been found in the ruins of the Aztecs of Mexico, and the Japanese and East Indians have colored metals for several centuries. There are three methods of producing colors on metals; namely, by heat-treatment, by applying a chemical solution; and by electroplating. For ordinary commercial work, the surfaces are usually colored by the application of some chemical solution. To secure beautiful color effects requires experience and the use of the proper chemicals. The shades and colors obtained with any solution vary for different materials, as slight changes in the composition of the material will produce different color effects, so that it is impossible to formulate any fixed rules. With a little practice, however, one can secure excellent results by following the instructions given in the section on COLORING METALS, Vol. II, p. 160, which contains general information on various coloring processes such as are used for finishing sheet-metal parts, the exposed metal surfaces of fire-arms, etc.

Corrosion of Iron and Steel. — The injurious effects resulting from the rust or oxides which form on the surfaces of iron and steel parts, especially where there is excessive moisture, can be avoided by applying to these surfaces some protective coating. This coating may be some form of paint which does not rapidly deteriorate, an oxide coating, or a thin layer of some metal which does not deteriorate readily when subjected to dampness. The section on CORROSION OF IRON AND STEEL, Vol. II, p. 213, is a general review of this subject, which is of importance to all users of iron and steel.

Protecting Metal Surfaces. — The most general method of protecting iron and steel against corrosion, aside from the use of paint, is by coating the surface with zinc. This is commonly known as "galvanizing," and a coating may be applied either by immersing the work in molten zinc, by means of an electrolytic bath, or by the sherardizing or vapor process. Owing to the universal need of adequate means of preventing corrosion, many other processes have been developed and the more important of these are described. The following articles should be referred to: GALVANIZING, Vol. III, p. 280; COWPER-COLES PROCESS, Vol. II, p. 232; SHERARDIZING, Vol. V, p. 363; LOHMANNIZING, Vol. IV, p. 243; GALVANIT PROCESS, Vol. III, p. 280; BARFF METAL PROTECTING PROCESS, Vol. I, p. 244; SCHOOP METAL SPRAYING PROCESS, Vol. V, p. 316; COSLETTIZING, Vol. II, p. 219; EPICASSIT, Vol. III, p. 63; BITUMASTIC ENAMEL, Vol. I, p. 372; JAPANNING, Vol. IV, p. 94; PAINTING MACHINE TOOLS, Vol. IV, p. 521; LACQUER AND LACQUERING, Vol. IV, p. 157; VARNISH, Vol. VI, p. 436; ENAMELING, Vol. III, p. 56; EFKALIN, Vol. II, p. 526; CALORIZING, Vol. I, p. 530; and INSULUMINUM, Vol. IV, p. 68.

STANDARD AND SPECIAL CUTTING TOOLS

MODERN machine tools have been developed to a high degree of perfection both as regards rapidity of production and accuracy in the finished product. It is apparent that this result is due to a careful study of all the fundamental points entering into the design, such as ample driving power, convenience of control, adequate speed and feed-changing mechanisms, substitution of automatic operation for hand control whenever practicable, and other important features intended to increase the mechanical efficiency and the rate of production. The machine itself, however, may be perfect in design and faultless in construction, but, if the auxiliary equipment necessary to adapt it to different classes of work is not planned and built with the same care, the good features of the machine may be of little practical value. Therefore, well-organized manufacturing plants, especially of the larger concerns, have planning and tool designing departments, where men of wide experience and ability devote their entire time to the design of the tools and auxiliary equipment needed for manufacturing operations. Such an organization is not feasible in many smaller shops or manufacturing plants, and frequently the design of such tools must be left to a draftsman who does general designing work. The course of study outlined in the following paragraphs is intended more especially for draftsmen who are not tool specialists, as well as for students interested particularly in the design of metal-working machines and their tool equipment; but the articles referred to will doubtless also be appreciated by many who may be classified as experts. These articles cover the tools used for different metal-cutting operations which are generally classified as "small tools," — that is, drills, counterbores, reamers, taps and threading dies, milling cutters, hobs, forming tools, and automatic screw machine tools. Those not familiar with different types of machine tools and general machine shop practice should study the course outlined in this GUIDE under the general headings "Machine Tools and Shop Equipment" and "Machine Shop and Toolmaking Practice."

Drills and Counterbores. — A great deal of the auxiliary tool equipment used on different types of machine tools is classified as "standard" or "commercial," because the tools are made to certain standard dimensions and can be purchased from manufacturers making a specialty of that class of work. Drills, counterbores, reamers, taps, etc., are examples of the standard "small tools," although frequently such tools are made to special forms or sizes in the shops where they are used, either because the required size is not obtainable or because a standard tool is not considered suitable. General information regarding the different kinds of drills in use, the proportions of different sizes, and the general methods of manufacturing drills are subjects dealt with in the article on DRILLS, Vol. II, p. 465. Counterbores, or tools of the class used for enlarging holes to form the seats for the heads of screws, etc., are quite frequently made in the shops where they are used. (See COUNTERBORES, Vol. II, p. 223.)

Reamers and Reamer Holders. — Holes that are produced simply by drilling are not accurate enough for many purposes, and reamers are used to secure smooth, straight holes of uniform diameter, especially in connection with interchangeable manufacture of high-grade machinery. When bolts must be accurately fitted in their holes, the latter are usually finished by reaming. Reamers are also applied in many other ways; some types are intended especially for enlarging drilled or cored holes rather than for producing a finished hole of uniform size. While reamers of various types may be obtained from manufacturers of small tools, a great many special reamers are made in the shops where they are used, because the size or form is odd and is not carried in stock by reamer manufacturers. General information on the subject of reamers will be found in the article on REAMERS, Vol. V, p. 240. Specific information on different types of reamers may also be obtained from the following articles: HAND REAMERS, Vol. III, p. 505; JOBBERS' REAMERS, Vol. IV, p. 143; SHELL REAMERS, Vol. V, p. 362; BRIDGE REAMERS, Vol. I, p. 505; CENTER REAMERS, Vol. II, p. 42; CHUCKING REAMERS, Vol. II, p. 108; LOCOMOTIVE TAPER REAMERS, Vol. IV, p. 239; PIPE REAMERS, Vol. V, p. 50; TAPER PIN REAMERS, Vol. VI, p. 180; REAMERS FOR TAPER SOCKETS, Vol. V, p. 246; in conjunction with the subject of reamers, see also REAMER HOLDERS, FLOATING, Vol. V, p. 237.

Taps and Threading Dies. — Taps are indispensable as a rapid means of cutting threads in holes for receiving machine screws, studs, bolts, or other threaded parts, and they also make it possible to produce readily threaded holes which are duplicates, within practical limits. Most of the taps in use are obtained from manufacturers of small tools, but special forms are often used, which differ from the accepted standard as to diameter and pitch of thread. Taps vary in form according to the class of work for which they are intended, some being designed for tapping by hand and others for use in a drilling machine or special tapping machine. As taps are needed on such a variety of work, many of them are intended for specific operations, such as tapping nuts, pipe fittings, etc. The section on taps, Vol. VI, p. 203, is in the nature of a general treatise, and specific information on different types will be found in the following separate articles: ACME THREAD TAPS, Vol. I, p. 24; BIT-BRACE TAPS, Vol. I, p. 372; BLACKSMITHS' TAPS,

Vol. I, p. 372; BOILER TAPS, Vol. I, p. 448; DIE TAPS, Vol. II, p. 382; GAS FIXTURE TAPS AND DIES, Vol. III, p. 307; HAND TAPS, Vol. III, p. 507; MACHINE NUT TAPS, Vol. IV, p. 267; MACHINE SCREW TAPS, Vol. IV, p. 269; PIPE TAPS, Vol. V, p. 51; SCREW MACHINE TAPS, Vol. V, p. 324; SQUARE-THREADED TAPS, Vol. V, p. 522; STAYBOLT TAPS, Vol. V, p. 544; TAPS, ADJUSTABLE, Vol. VI, p. 219; TAPPER TAPS, Vol. VI, p. 193. These articles contain information of value both to the draftsman interested in tap design and the toolmaker who may be called upon to make a special tap. Threading dies, which are the tools used for cutting external threads, are also indispensable in every machine shop. Dies, however, are not made in so many different types as taps, although they vary considerably in design; some are solid, others have inserted chasers or thread-cutting blades, and there is also the self-opening type, which is quite extensively used on turret lathes and automatic turning machines. (See DIES, THREADING, Vol. II, p. 377, and the paragraph on self-opening die-heads, Vol. VI, p. 369, in the section on TURRET LATHES.) In connection with the subject of dies, reference should be made to Vol. II, p. 86, in the article on CHASERS.

Milling Cutters and Hobs. — The milling process is applied to such an endless range of work that the cutters used on milling machines naturally vary greatly in form. Some are intended for general milling operations and others for one specific line of work. While many milling cutters in use are commercial tools, obtained from cutter manufacturers, a great many special cutters are made in different shops. The section on MILLING CUTTERS, Vol. IV, p. 367, contains a great deal of information relating to milling cutter design and the methods of making cutters, including types of milling cutters, methods of milling the teeth in cutters, grinding cutter teeth, and the proportions of different types of cutters.

A great many of the gears used in various kinds of machinery are cut by the hobbing process, the principle of which is explained in the section on GEAR-CUTTING MACHINES, Vol. III, p. 331. The hobbing operation, like most other gear-cutting processes, requires the use of a cutting tool that is designed with reference to the principles of gearing, and which is very accurately made. Owing to the importance of this subject, it has been treated at length in the articles on HOBS FOR SPUR AND SPIRAL GEARS, Vol. IV, p. 13, and also HOBS FOR WORM GEARS, Vol. IV, p. 22. (See also HOBS FOR RATCHETS AND SPLINES, Vol. IV, p. 12.)

Forming Tools. — Forming tools are used ordinarily in some class of lathe or turning machine for finishing surfaces that are either concave, convex, or irregular in shape. The cutting edges of the tool are carefully filed or ground to the contour or shape required, so that, with a tool of this kind, duplicate parts may be readily produced. Form or forming tools are extensively used on automatic screw machines in connection with regular manufacturing operations, and also in toolmaking for turning form milling cutters and for similar operations. The article on FORMING TOOLS, Vol. III, p. 193, is intended especially for those interested in toolmaking methods. This article deals with types of forming tools, methods of making straight and circular tools, the finishing of tools by grinding, and the calculations for determining the proper allowance on radial and angular measurements. (See also GEAR-CUTTER FORMING TOOLS, Vol. III, p. 319.)

Special Turning Tools. — The extent to which special tools should be used is often a difficult question to decide. Special tools are usually expensive to make, but if they greatly increase the rate of production, the cost may be of little consequence as compared with the reduction in manufacturing cost. The relation between the tool expense, the saving effected by its use, and the amount of work to be done are the important points to consider. Many special tools of the class used for turning operations on different types of machines are described in the section TURNING TOOLS OF SPECIAL DESIGN, Vol. VI, p. 343. A study of these designs will show to what classes of work such tools have been applied, and may suggest ways of applying the same general principles to tool designs for other machining operations.

Automatic Screw Machine Tools. — There is no type of machine tool which requires as many special cutting tools as the automatic screw machine. This is due to the fact that all movements are mechanically and automatically controlled, and many tools must be made to meet the requirements of each different class of work. Tools are needed for turning special shapes and for such operations as boring, recessing, threading, and knurling, under a great variety of conditions. The section on AUTOMATIC SCREW MACHINE TOOLS AND OPERATIONS, Vol. I, p. 150, is intended both for tool designers and for the users of screw machines. This section includes various classes of cutting-off tools, milling, counterboring and reaming tools, box-tools, thread-cutting tools, etc. In many cases, the methods of applying these tools are illustrated by practical examples.

Chips from Metal-cutting Tools. — The chips removed by different types of metal-cutting tools should be considered when designing a tool, as they often have a decided effect on the design. The flutes of a twist drill or reamer are necessary in order to provide space for the chips, and other cutting tools, as well as work-holding fixtures, are varied more or less in their design either to protect bearing surfaces from chips, or to prevent chips from interfering with the location of the work. The article dealing with this subject, Vol. II, p. 103, is of especial importance to the designer of jigs and fixtures.

POWER PLANTS AND EQUIPMENT

THE purpose of a power plant is to transform the energy derived from some natural source into such a form that it can be applied to the performance of useful work. The windmill, which is driven by the action of air currents against inclined blades or sails, and the primitive form of water-wheel with paddles, represent simple forms of power plants. In each case, the moving elements impart rotary motion to a wheel or shaft which is capable of revolving against a certain amount of resistance and of doing mechanical work. In modern power plants, this general principle is adhered to, some fluid under pressure and capable of motion being used to impart a rotary movement to a mechanical device, such as a water turbine, steam engine, steam turbine, or gas engine. The water turbine is located at some point below the level of a body of water, and, when a column of water is conveyed to the turbine through a suitable flume, a pressure is exerted against the turbine wheel which causes it to rotate as the water passes through it to a lower level. The steam engine or steam turbine is driven by the latent heat energy in coal or other fuel, which is used to generate steam under pressure in an enclosed boiler to which the engine or turbine is connected. The energy stored in gas, and in gasoline or other oil, is used in a very direct way for driving internal combustion engines, as the combustion of the fuel and the generation of pressure takes place in the engine cylinder itself.

Prime Movers. — All of these mechanical devices for transforming the energy derived from any form of fuel, or from air or water in motion, into mechanical action or work are known as "prime movers." Reciprocating steam engines, steam turbines, gas, gasoline or oil engines, and windmills, are all prime movers; but the electric motor is not a prime mover, because it merely transforms electrical energy into mechanical energy. Back of every motor there is the dynamo or generator for generating the electric current, which, in turn, is driven by a prime mover, such as a steam engine, or a steam or water turbine. These elementary points are referred to in order to give the student who commences the study of power machinery a general idea of the relation between different forms of apparatus used in power plants. Most power plants, at the present time, are equipped with engines or turbines driven by steam, although water turbines are common where water power is available. In studying the subject of steam power plant development, it is apparent from what has preceded that there are two broad divisions; one pertains to the generation of steam in boilers, and the other to the types of prime movers — engines or turbines — in which the steam is utilized to perform mechanical work. The great problem in boiler design and operation, and one which has engaged the attention of mechanical engineers since the inception of this method of power development, is to produce the greatest amount of steam from a given weight of fuel. The designer of the engine or turbine is concerned, principally, with the amount of work which the engine is capable of doing with a given amount of steam.

Steam Engines of the Reciprocating Type. — The steam engine having a reciprocating piston, which through a connecting-rod and crank revolves a shaft, depends for its operation upon the pressure of steam acting against the piston first in one direction and then in the other. While the principle of operation is very simple, engines of different design vary greatly in regard to the mechanical details required to control the admission and release of steam to and from the cylinder, to regulate the speed, to prevent the leakage of steam past the joints of moving parts, to provide for adjustment of members subject to wear, and to supply the lubrication of the bearing surfaces. The general arrangement and operation of various types of engines are described in the section on STEAM ENGINES, Vol. VI, p. 1; it would be preferable for most students of this general subject to read this section as far as the paragraph headed *Formulas for Steam Engine Design*, on p. 34, as the remaining part deals with steam engine design, which will be considered later.

Steam Turbines. — The steam turbine has replaced the reciprocating type of steam engine in many power plants, as it is capable of doing a larger amount of work for a given consumption of steam when used under favorable conditions, requires less space for developing an equal amount of power, and operates with much less vibration. The operation of the steam turbine depends upon the action of steam moving at high velocity and striking against blades or vanes so formed and arranged that the part to which they are attached will rotate. This principle is very old and its successful application at the present time in conjunction with the development of modern types of steam turbines is an interesting study. The principal types of turbines and their characteristics are dealt with in the section on STEAM TURBINES, Vol. VI, p. 36.

Boilers for Power Plants. — The generation of steam for use in power plants requires boilers capable of withstanding the steam pressures that are to be developed; means of supplying the boilers with water, and of heating the water by the combustion of coal or other fuel; apparatus to prevent an excessive accumulation of pressure in the boiler; a method of regulating the draft and, consequently, the rate at which steam is produced; together with auxiliary apparatus designed to economize in the use of fuel by eliminating unnecessary waste.

For descriptions of different types of boilers, see Boilers, Vol. I, p. 414, and Boiler Furnaces, Vol. I, p. 408. The coal for coal-fired boilers is usually supplied by hand shoveling, but mechanical stokers are used in many of the larger power plants; typical designs are described in Vol. VI, p. 77. Methods of feeding oil fuels are referred to in the article Oil Burners for Boilers, Vol. IV, p. 502. Methods of feeding water to boilers and regulating the supply are dealt with in Vol. I, p. 395. (See also Injector, Vol. IV, p. 59, and Boiler Feed-water Heaters, Vol. I, p. 407.) The deposits left in boilers from feed water and their corrosive action are often the cause of much trouble, and the composition and purification of feed water is, therefore, covered in Vol. I, p. 396. Since the generation of steam depends upon the combustion of some fuel, the properties and uses of different fuels, as well as the principle of combustion, should be understood. (See Fuels, Vol. III, p. 218; Coal, Vol. II, p. 145; and Combustion, Vol. II, p. 169.)

Improving Efficiency of Power Plants. — The steam power plant, at its best, is very inefficient, although great improvements have been made in the development of different forms of apparatus for increasing the efficiency of engines and boilers. The object of this auxiliary apparatus may be either to increase the work obtained from the engine for a given steam consumption, or to increase the amount of steam generated for a given amount of coal or other fuel. In order to obtain all the work from steam that it is capable of doing, it should be allowed to expand as much as possible. This point may be illustrated by comparing steam under pressure with a compressed spring, which, to perform all the work that it is capable of, must expand to its full length. It is not practicable to obtain complete steam expansion in a single cylinder, but by allowing the steam to pass through two or more cylinders, as in multiple-expansion engines, a much better rate of expansion may be obtained; still better results are possible with modern steam turbines; furthermore, by connecting the exhaust pipe of the engine or turbine with an enclosed chamber in which the steam is condensed, and from which practically all air has been exhausted, the expansion may continue until the steam pressure falls far below the atmospheric pressure. The different forms of condensing apparatus for condensing exhaust steam and reducing the pressure on the exhaust side of engines are described in the article on Condensers, Vol. II, p. 175. For descriptions of different types of pumps used in conjunction with these condensers, see Air Pumps, Vol. I, p. 52. Among the different forms of apparatus used in connection with the generation of steam, for reducing direct heat losses, may be mentioned Economizers, Vol. II, p. 525, and Boiler Feed-water Heaters, Vol. I, p. 407. The use of Superheaters, Vol. VI, p. 122, to heat steam to a higher temperature to reduce the losses from cylinder condensation is another important development.

Steam Engine Design. — The design of a steam engine involves proportioning the cylinder with reference to the amount of power to be developed, providing suitable means for controlling the steam supply and speed, arrangement of the wearing parts so that lost motion resulting from wear can be eliminated, and the making of all parts of such form and size that they will safely withstand any stresses due to ordinary usage. The designer has a certain amount of preliminary data as a basis to work from, and from this data evolves the design by following the fundamental principles governing the operation of prime movers of this class. The general method of procedure is explained in the section on Steam Engines, Vol. VI, p. 1. The following articles should also be referred to: Valve Diagrams, Vol. VI, p. 378; and Piston Packing Rings, Vol. V, p. 79.

Valve Setting. — A steam engine of the reciprocating type cannot operate properly unless the valve (or valves) controlling the admission of steam to the cylinders — the point at which steam is cut off and used expansively, and the point of release or exhaust — is adjusted to act at the right time relative to the movements of the piston. Valve setting is regarded as difficult by many machinists in engine-building and railway shops, but it is really quite simple, if the underlying principle and the reasons for different adjustments are understood. The section on Valve Setting, Vol. VI, p. 387, begins with the simplest problems in valve adjustment, and then deals with the variations in procedure for different types of engine valve-gears.

Gas and Oil Engines. — The steam system of power generation is very indirect, as the heat from the fuel is first transmitted to water which, after being converted into steam, either exerts pressure upon a piston, or, after attaining high velocity, impinges upon the blades of a turbine rotor. With this system, even with the most highly developed types of apparatus, only about 15 per cent of the heat in the coal is converted into useful work. With gas or oil engines, a much higher efficiency is possible, as an explosive mixture of air and gaseous fuel or oil spray is ignited directly in the cylinder, where the pressure resulting from the combustion and the rise of temperature is utilized immediately to propel the engine piston. With well-designed internal combustion engines 25 or 30 per cent of the heat of the fuel (in the gaseous form) may be transformed into mechanical energy or useful work, and even higher efficiencies have been obtained occasionally. Owing to the industrial importance of engines of this class for driving automobiles, motor boats, and as prime movers in power plants, a knowledge of the general principles governing their operation and design is essential to the mechanical engineer and many other men engaged in different lines of mechanical work. The section on Gas and Oil Engines, Vol. III, p. 282, describes the principal types, the means of obtaining explosive mixtures of air and gas or oil spray, and includes information on the liquid fuels used in internal combustion engines, methods of cooling cylinders, and troubles commonly encountered and their causes. The article on Diesel Engines, Vol. II, p. 370, should also be studied in this connection. In addition, GAS TURBINES, Vol. III, p. 317, and GAS PRODUCERS, Vol. III, p. 309, are subjects to be included in this course.

Lubricating Oils. — Friction between the moving parts of engines not only increases their resistance to motion and, thereby, wastes energy by reducing the amount that is left for the performance of useful work, but friction also often causes bearing surfaces to be seriously injured. Without some form of lubricating oil, practically all machinery, as it is now constructed, would be useless. Lubricants, however, like the machines and mechanisms to which they are applied, vary greatly in quality and effectiveness. Many lubricants contain injurious adulterants to make them cheap, and what would be a good lubricant for one class of mechanism would be poor for another class. A lubricant must have enough body, or consistency, to withstand the bearing pressure, and a lubricant which would be suitable in an ordinary bearing might be useless in an engine cylinder, owing to the effects of the higher temperatures. The section on LUBRICANTS, Vol. IV, p. 244, covers different classes of oils, their properties, objectionable impurities, methods of testing, and kinds of lubricants for engine cylinders and different classes of machinery. (See also GRAPHITE, Vol. III, p. 428.)

Arrangement of Power Plants. — Modern power plants, especially of the large sizes for generating electrical power, contain such a mass of equipment used directly or indirectly either in the generation of steam or in utilizing the energy developed, that the application of these various forms of apparatus and their arrangement should be carefully considered in laying out a new power plant. The section on POWER PLANTS, Vol. V, p. 129, covers steam power plants, steam-electric and hydroelectric plants, and deals with their location, constructional features, coal-handling equipment, and the general application and adaptability of apparatus common to power plants. (See also CHIMNEYS, Vol. II, p. 101.)

Water-wheels and Turbines. — One of the earliest forms of power machinery was the water-wheel of the form equipped with paddles which on one side of the wheel engaged a moving stream of water and thus received a rotary motion. While this principle of utilizing the energy of a moving column of water to develop mechanical power is employed in some of the largest and most modern power plants of the present day, the apparatus used has changed considerably in the process of evolution both in appearance and effectiveness. The moving stream, when used in the direct way described, is not capable of developing very great power, and engineers finally realized that it was necessary to concentrate the energy by allowing the water under pressure to escape at a relatively high velocity and pass the blades or vanes of a wheel so formed that the downward flow of water caused the wheel to revolve. A great deal of study and experimenting was necessary to determine what form of blade would give the highest degree of efficiency. As a result of this work, in conjunction with present-day possibilities of manufacturing almost any form of machine that can be designed on paper, the primitive paddle wheels driven by a moving stream have been replaced by turbine wheels capable of developing thousands of horsepower. Various forms of wheels driven by water power are described in the article on WATER-WHEELS AND TURBINES, Vol. VI, p. 444. This article also gives the elements of the theory of hydraulic power.

Pipes and Tubes. — Pipes and tubes are usually made of wrought iron, steel, cast iron, brass, or copper. Although pipes are used universally and in innumerable ways, the mechanical engineer generally considers piping as applied either directly to the power plant or in conjunction with pumps or other mechanical apparatus, as a means of conveying some fluid under pressure, such as water, steam, or compressed air. The general subject of piping includes the standard dimensions that have been adopted, the fittings and means of joining pipe sections together, the bending of pipes to different shapes, and the methods of manufacture. The following articles form a complete treatise on this subject: PIPE, Vol. V, p. 22; PIPE FITTINGS, Vol. V, p. 37; PIPE JOINTS, Vol. V, p. 46; GASKETS AND GASKET RETAINERS, Vol. III, p. 308; VALVES, Vol. VI, p. 383; PIPE SUPPORTS, Vol. V, p. 50; PIPE BENDING, Vol. V, p. 28; PIPE EXPANSION BENDS, Vol. V, p. 36. PIPING FOR POWER PLANTS, Vol. V, p. 56; TUBE EXPANDING, Vol. VI, p. 340; PIPE COLORS, Vol. V, p. 35: TUBE AND PIPE MANUFACTURE, Vol. VI, p. 331.

ELECTRICITY AND ELECTRICAL MACHINES

WHILE many of the machines used in the industries either for producing power or for operations on materials of different kinds have been gradually developed during a long period covering a century or more, electrical machinery and devices have been developed practically within the comparatively short space of thirty odd years. In no field of industrial progress has the development been so rapid. The fundamental laws relating to the electric current have been known for a hundred years or more, but it was not until in the eighties that electricity was applied for practical purposes to an extent that made it an important factor in industrial development. The first electrical generators and motors were not very reliable, and breakdowns with consequent interruptions in the service were common. In the short space of a quarter of a century, however, these machines have been brought to a perfection where they may be considered at least as reliable as other forms of power-plant machinery, and, in addition, require comparatively little attention.

The ENCYCLOPEDIA deals very completely with electrical machines and devices, and, in addition, contains a comprehensive review of the subject of electricity and magnetism, dealing with the fundamental laws of the electric current and its properties. The electrician or electrical engineer will find the ENCYCLOPEDIA useful for rapid reference upon subjects relating to the use and application of electrical machines and devices, and the student may also use the articles contained in this work for a course of reading which will give him a general knowledge of the subject of electricity, electrical machinery, accessories and appliances. It should be understood at the outset, however, that the study of electricity may be found somewhat more difficult than the study of the ordinary mechanical subjects. When dealing with a steam engine, for example, we can see and comprehend the mediums through which the forces at work act. The electric current, however, is not visible, and the imagination must be drawn upon to aid the student in his work.

Terms used in Electrical Engineering. — In studying such a subject as electricity, where a great many terms are used that are not commonly employed in dealing with mechanical subjects, the student will often find many expressions the meaning of which he does not understand. In that case, he is referred to the index of the ENCYCLOPEDIA, which will generally direct him to a definition of the particular term or expression in question, but it would also prove helpful to the student of electricity and to the reader who expects to make considerable use of the electrical sections of this work for reference purposes, to carefully study those sections of the article on STANDARDIZATION RULES, Vol. V, p. 528, which give definitions of electrical machinery and expressions used in electrical engineering. Often, when reading an article, the whole meaning may be obscured if a single word is not properly understood. To understand the terms used in engineering in general, and in electrical engineering especially, is, therefore, highly important, in order to be able to make the best use of the ENCYCLOPEDIA. While the ENCYCLOPEDIA is not intended to be a dictionary defining terms or words of all kinds that may be used in engineering, it will, nevertheless, be found that most of the expressions and words used in electrical engineering have been properly defined, either in the section on standardization rules already referred to, or in some treatise on electricity or electrical machinery in the ENCYCLOPEDIA, to which the index will refer the reader.

Main Classes of Electrical Apparatus. — There are two electrical machines that may be considered basic; these are the *generator* which produces the electric current so that electric energy may be sent through a wire or conductor to a point at a distance, and the *motor* which at this point changes the electrical energy to mechanical energy for driving machinery of different kinds. All other electrical machines may be considered as accessories or auxiliaries to these two basic machines. Converters and transformers are used for changing current of one kind into current of another kind. Controllers and switches are used in the operation of motors and generators in order to control or cut off current as required. Storage batteries are used for the storing of electrical energy, as produced by a generator, until such time as it is required for use. In addition to the use of electric current for power purposes in motors, there is also the great field of electric lighting, where the electric current is used in various ways for producing illumination. It is also used, in the industries, for the heating of furnaces; for electroplating; and, in metallurgy, for the refining of metals. In fact, electricity, comparatively unknown thirty years ago, has come to be one of the great necessities of modern life, playing an important part in all industrial plants, railway operation, lighting, telegraphy, telephony, etc.

Electricity and Magnetism. — In studying the subject in a systematic manner, the student would begin with the section on ELECTRICITY AND MAGNETISM, Vol. II, p. 527, reading first the general introduction to the subject there given, dealing with the electric current, magnets, and magnetism, omitting, perhaps, at first such parts of the treatise as contain formulas giving the relation between different electric and electromagnetic quantities. To these formulas he may return later when he has attained a fair general understanding of the subject as a whole. This reading should be continued up to and including the paragraph on *Static Phenomena*, Vol. II,

p. 535. The foundation has now been laid for further study of the subject.

Many of the principles of electricity are also dealt with in brief separate articles in their alphabetical order in the ENCYCLOPEDIA, often somewhat more completely than in the general article on electricity and magnetism, and the student might sometimes find it helpful to refer to these separate references. For example, OHM'S LAW, Vol. IV, p. 501, gives the formulas and expresses the relation between current, electromotive force, and resistance in a somewhat more popular form than is done where the same subject is referred to in Vol. II, p. 532. The student, however, must make himself familiar with the use of formulas before taking up a thorough study of the subject of electricity, because, in a number of instances, he will find it necessary to be able to properly interpret the use of signs and symbols in formulas and equations. (See FORMULAS, Vol. III, p. 201.)

Principal Applications of Magnetism. — The general treatise on electricity and magnetism referred to in the preceding paragraph gives but a brief review of the elementary principles of magnetism. The practical applications of magnetism in industrial work, however, are manifold. In machine shop practice, magnetic chucks are used to an ever increasing extent, and a very complete treatise on this subject will be found in Vol. IV, p. 290. This treatise deals with various practical designs of magnetic chucks and gives directions for the design and construction of these devices. The making of permanent magnets is dealt with in Vol. IV, p. 303, and the application of electromagnets to the handling of iron and steel ingots and plates, in the article on LIFTING MAGNETS, Vol. IV, p. 203.

Direct-current Generators and Motors. — The elementary principles of the electric generator and motor are explained in Vol. II, pp. 531 and 532, from which it is understood that there are two kinds of generators and motors, direct-current and alternating-current. In studying the subject further, the student should turn to MOTORS, DIRECT-CURRENT, Vol. IV, p. 474, and proceeding from the beginning of the article he should continue to study as far as p. 481, to the paragraph *Winding an Armature of the Series Type*. The paragraphs following, relating to the winding of a motor, would be studied only in case the student were actually engaged in the design or construction of direct-current motors. GENERATORS, DIRECT-CURRENT, Vol. III, p. 398, should now be studied, the motors being studied before the generators, because the explanations of the elementary action of the motor would be helpful in understanding the action of the generators.

Alternating-current Generators and Motors. — The subject of alternating currents is not an easy one, and requires considerable application on the part of the student. The general principles are first studied, beginning with the paragraph on *Alternating Currents*, Vol. II, p. 536, continuing to the end of the article. A good knowledge of the principles of algebra and trigonometry is required in order to grasp the theory of alternating currents. Alternating-current or synchronous generators are dealt with in Vol. III, p. 388, and alternating-current motors, in Vol. IV, p. 462. It will be found that both in the case of the generators and motors the theoretical considerations are more prominent than in the case of direct-current generators and motors, because of the fact that the problems involved in alternating-current machinery are not so simple as those in direct-current machines. Students who are interested in the application of electrical machines, rather than in the principles upon which they work, could pass by the more difficult sections of alternating currents and proceed with other subjects outlined in this course, which do not require an understanding of the theory of alternating currents.

In addition to the direct- and alternating-current generators dealt with, there are some special classes of generators described in separate sections: The MAGNETO (Vol. IV, p. 301), which is simply a small electric current generator; GENERATORS, INDUCTION, Vol. III, p. 405, which are essentially induction motors driven above their synchronous speed; and GENERATORS, INDUCTOR, Vol. III, p. 405, which are synchronous generators in which both the field and armature winding are stationary and only the pole pieces revolve. All alternating-current generators are dependent upon an external source of direct current for magnetizing their fields, the current being furnished by auxiliary devices or machines known as EXCITERS, Vol. III, p. 72.

The unit of power for all electrical work is the KILOWATT, Vol. IV, p. 154, but, in the case of alternating-current machines, the term KILOVOLT-AMPERE (Vol. IV, p. 154) is used to express the apparent power. It is important that these two units be correctly understood.

Machines for Transforming Electric Current. — Due to the fact that electric current may sometimes be generated and transmitted more easily in one form and at a certain voltage, and more suitably used in another form and at another voltage, different machines and devices have been designed for changing or transforming one kind of current into another and also for transforming the voltage from one value to another. One of the transforming devices used for this purpose is known as a MOTOR-GENERATOR SET, Vol. IV, p. 457. By means of motor-generator sets, direct current of a given voltage may be transformed into direct current of a different voltage; alternating current may be changed into direct current; and alternating current of one frequency may be changed into alternating current of another frequency. The machines used for changing direct current of one voltage into direct current of another voltage are known either as *Boosters*, Vol. IV, p. 457; *Balancers*, Vol. IV, p. 458; or *Dynamotors*, Vol. IV, p. 460, the dynamotor being used for transforming high-voltage direct current into one of lower value. Motor-generator sets for transforming alternating current to direct current, Vol. IV, p. 460, are used extensively on lighting, power, and railway systems, and frequency changers, Vol. IV, p. 461, are used for converting an alternating current of one frequency to another, without a change in the number of phases or in the voltage.

Another kind of electrical machine used for converting alternating current into direct current is known as a *synchronous converter*. A similar type of machine used for converting direct current into alternating current is known as an *inverted synchronous converter*. Both types are frequently referred to as *rotary converters*. These machines are dealt with in the section CONVERTERS, SYNCHRONOUS, Vol. II, p. 191.

A transformer is a stationary apparatus used for changing or transforming alternating current of one voltage to alternating current of a higher or lower voltage. When a low voltage is changed to a higher voltage, the apparatus is known as a *step-up transformer*, and when a high voltage is changed to a lower voltage, as a *step-down transformer*. These devices are treated in the section on TRANSFORMERS, Vol. VI, p. 305. Alternating current may also be changed into direct current by means of mercury arc rectifiers. These are generally used in connection with transformers which step down the voltage of the current, which is then changed into direct current by means of the rectifier. (See RECTIFIERS, MERCURY ARC, Vol. V, p. 248.)

PHASE-CONVERTER, Vol. V, p. 11, and PHASE-ADVANCERS, Vol. V, p. 10, are used in connection with alternating-current machines. The function of the phase-advancer is to convert a single-phase load into a poly-phase load, and to counteract the difficulties due to taking single-phase loads from poly-phase systems. Phase-advancers, also known as "phase-multipliers" are used for improving the power factor of induction motors. SYNCHRONOUS CONDENSERS, Vol. II, p. 181, are used for power factor correction and for maintaining a constant voltage by power factor control. All these devices may be considered as auxiliary apparatus used in connection with alternating-current machines to improve and increase their range of operation.

Electric Machinery Operation. — Many students who would use the ENCYCLOPEDIA as a condensed text-book on electrical machinery, and who might not desire to go into a detailed study of the various auxiliary machines referred to in the preceding paragraphs, could proceed directly from the study of generators and motors to that of electric machinery operation as dealt with in a comprehensive manner in the section beginning on page 1 of Vol. III. This section is divided into four distinct parts, the first dealing with direct-current generators and motors, p. 1; the second, with alternating-current generators and motors, p. 4; the third, with transformers, p. 9; and the fourth, with synchronous converters, p. 11. This section of the ENCYCLOPEDIA deals especially with the troubles and difficulties that are likely to be encountered in the operation of electrical machinery, and is especially intended for operators of electrical apparatus. It is thoroughly practical in its nature, requiring no preliminary theoretical knowledge except an elementary understanding of the electric current and of the construction of the electrical machines dealt with, as explained in the articles devoted to these machines. The theoretical principles of electricity and magnetism, or of motors and generators, would not be required in order to make use of this section.

Electric Measuring Instruments. — While in this GUIDE the electric measuring instruments are mentioned at this point, it would be quite satisfactory to study the methods of measuring electric currents, voltages, resistances, etc., at an earlier stage. In fact, the study of electric measuring instruments might be carried on simultaneously with the study of electrical machines, it being only necessary to properly understand the subject of the principles of electricity and magnetism as outlined in the article on that subject, Vol. II, p. 527. The different electrical measuring instruments are all dealt with in one section, Vol. III, p. 13. This treatise includes specifically current-measuring instruments or ammeters, p. 15; voltage-measuring instruments or voltmeters, p. 19; and power-measuring instruments, or wattmeters, p. 21; power factor meters, p. 22; frequency meters, p. 22; ampere-hour meters, p. 23; watt-hour meters, p. 24; and resistance measuring instruments or ohmmeters, p. 25. In addition to these main types of instruments, many miscellaneous electrical measuring instruments are briefly referred to in this section. Electric pyrometers for measuring temperatures by means of thermo-electric effects are dealt with in the article on PYROMETERS, Vol. V, p. 217.

Electric Controlling Devices. — Broadly defined, electrical machines and devices might be divided into four general groups: Those used for generating electric energy; those used for transmitting it from the generating source to the point where it will be used; those employed for changing it again into mechanical or other energy; and, finally, those employed for controlling the current at the various stages. In the broad sense, therefore, electric controlling devices include circuit-breakers, switches, relays, reactances, lightning arresters, fuses, etc.; in a more limited sense, they include only such apparatus as starting rheostats; speed regulating or controlling rheostats, generally referred to as speed regulators and controllers; and such devices as compensators and auto-transformers. It is in this latter sense that the expression "controlling devices" is used in the section devoted to it in Vol. II, p. 185. In this article, a review of the development of controllers and motor starters is given, and the different types of hand-operated, power-operated, and automatic controllers are described.

Circuit-breakers — devices used for automatically opening an electric circuit when an abnormal condition exists in the circuit — are dealt with in the article on CIRCUIT-BREAKERS, Vol. II, p. 115, which covers the different types of circuit-breakers and their construction, the means used for tripping circuit-breakers, and the calibration and connections of these devices. Fuses serve a purpose similar to that of circuit-breakers, except that they act in a different manner. A circuit-breaker mechanically opens the circuit under abnormal conditions, while a fuse is made of a material that will melt at a predetermined current value and thus opens the circuit and protects it against abnormal current conditions. (See FUSES, Vol. III, p. 265.) Switches are used for closing or connecting electric circuits either by hand or automatically, according to the conditions. There are a very great number of electrical switches which can be grouped into two main groups: SWITCHES, AIR-BRAKE, Vol. VI, p. 155, and SWITCHES, OIL, Vol. VI, p. 166. RELAYS, Vol. V, p. 249, are used in connection with the automatic tripping of circuit-breakers or oil switches on the occurrence of abnormal conditions in the circuit. The relay disconnects that part of an electric system in which a fault has occurred from the rest of the system with the least practicable delay. Relays are also used for many other purposes.

Current-limiting reactances or reactance coils are used for reducing the flow of current in an alternating-current circuit, and, hence, come under the head of current controlling devices. This class of apparatus is dealt with in the article on REACTANCE, CURRENT-LIMITING, Vol. V, p. 235. Lightning arresters, which are used to protect an electric circuit against the high voltages caused by abnormal atmospheric conditions, are of several different designs, which are briefly described in the section on LIGHTNING ARRESTERS, Vol. IV, p. 208. Electrical measuring instruments, switches, etc., are generally arranged for the convenience of the operator on what is known as a "switchboard." The general construction of switchboards and the arrangement of the apparatus that is placed on them is comprehensively dealt with in the article on SWITCHBOARDS, Vol. VI, p. 139.

Primary and Storage Batteries. — Instead of producing electric current by means of a generator, small amounts of current may be produced by batteries or cells generally known as *primary batteries*, or *primary cells*, in order to distinguish them from *storage* or *secondary* batteries, which are used for storing up electric energy for future use. Primary batteries were among the early means of producing an electric current. Many textbooks on electricity begin with the theory of primary cells, and quite logically so, because of the importance of this means of producing an electric current in the early investigations into the characteristics of electricity. Today, however, electric current produced by batteries is of comparatively small importance, when considered in connection with the current produced by generators. Batteries are used only for producing current when the amount needed is so small that the cost of materials consumed in the batteries may be disregarded on account of the small attention required and the constancy of the source of the supply of current; hence, batteries are used extensively for operating bells, and also for telegraph and telephone service.

Secondary or STORAGE BATTERIES, Vol. I, p. 253, are used for storing energy in the form of chemical energy and transforming it, when required, into electrical energy for use in motors or for other purposes. Storage batteries may be either lead batteries, Vol. I, p. 254, or alkaline batteries, Vol. I, p. 260. The subject of batteries, both primary and storage, can be profitably studied without reference to the other articles on electrical machinery contained in the ENCYCLOPEDIA.

Power Stations and Transmission Lines. — Power stations for producing electrical energy may be of two kinds: Steam-electric power plants, and hydroelectric power plants. In a few instances, electric generators are also driven by gas engines. The general arrangement of both steam engines and hydroelectric power plants is dealt with in the section on POWER PLANTS, Vol. V, p. 129, the steam-electric power plant being specifically referred to on page 130 and following pages, and the hydroelectric plants on page 143 and following pages. This section deals with the general arrangement of the machinery and auxiliaries in the plant, giving information about the building, illumination, coal-handling equipment, boilers and accessories, steam turbines, piping, and electrical apparatus. The section dealing with hydroelectric power stations gives similar detailed information relating to the best arrangement for this class of power plants. Electrical substations are dealt with in the same general section (Vol. V, p. 147), small outdoor industrial substations being dealt with in greater detail in the article SUBSTATIONS, INDUSTRIAL, Vol. VI, p. 119. From the power station, transmission lines convey the electrical energy to the point where it is to be used. The construction of transmission lines is highly important, as the losses due to improper construction are very serious and constitute one of the greatest losses in the use of electrical power. The article on TRANSMISSION LINES, Vol. VI, p. 310, deals comprehensively with this subject. In this connection, the article on INSULATION, ELECTRICAL, Vol. IV, p. 59, may also be studied. It deals, however, not only with the insulation used directly or indirectly in connection with transmission lines, but also with insulation used in connection with electrical machines of all types.

APPLICATIONS OF ELECTRICITY

THE applications of electrical energy with which the ENCYCLOPEDIA deals are: 1. The uses of electric current for power, that is, for motor-driven machinery of various kinds — primarily, machine tools and hoisting apparatus. 2. Electric lighting — an application familiar in a general way to everybody. 3. The application in metallurgy for the refining of metals. 4. For electroplating. Under the head of electrometallurgy would be included the use of the electric current in electric furnaces, which application is becoming of great importance. It is feasible to study the applications of the electric current without making a detailed study of electricity and electrical machines. A brief review, however, of the subject of electricity, covering that part of the article on ELECTRICITY AND MAGNETISM which is found in Vol. II, pp. 527–535, inclusive, will prove useful, as well as of MOTORS, DIRECT-CURRENT, Vol. IV, p. 474, and the sections on MOTORS, ALTERNATING-CURRENT, Vol. IV, p. 462, which do not deal with the theory or the design of motors of this kind.

Motor Drive for Machine Tools. — The application of electric motors to machine tools is a subject which is most closely allied to the field which the ENCYCLOPEDIA covers. This subject, therefore, has been given a prominent part in the work, and would naturally be studied first by those who are engaged in the machine-building field and need a knowledge of the use of motor drives in machine shops. The information on this subject is covered in the article MOTOR DRIVE FOR MACHINE TOOLS, Vol. IV, p. 441, which deals first with the two different types of motor drive: (1) Individual — when an electric motor is used for each separate machine — and (2) group drive — when a number of machines are grouped together and driven by a short lineshaft which receives its motion from an electric motor driving the whole group. The article also covers the three kinds of direct-current motors, the series-wound, shunt-wound, and compound-wound, which are used for driving machine tools. Each of these three types has characteristics which make it suitable for certain classes of machines. Motors for machine tool drives may also be divided into two classes — constant-speed and variable-speed; each type is suited for certain machines and conditions. After having reviewed these general requirements of motors, the student will proceed with the treatise on the direct application of motors to machine tools, on page 445. The requirements for different classes of machines are given in the section *Motors for Different Kinds of Machine Tools*, on page 449. Here the requirements for lathes, screw machines, drilling machines, boring machines, grinding machines, planers, shapers, slotting machines, milling machines, punches, bending rolls, shears, and woodworking machines are briefly described. For ready reference, tables of the horsepower required for machine tools and forging machinery are included (Vol. IV, p. 451).

The man interested in the application of different types of motors to machine tools would not need to proceed any further with this article, as the general requirements of the types of motors used and their application have now been covered. The designer, however, who has to apply motors to existing machine tools, and who has to provide supports for the motors, will find the paragraphs relating to electric motor supports (Vol. IV, pp. 453–457) of considerable assistance, as here are given not only the formulas by means of which the strength of these supports may be calculated, but also illustrations and designs of a number of different kinds of supports suitable to be attached either directly to machine frames or to the shop structure itself — walls, posts, or beams.

Motor Drive for Woodworking Machines. — Electric motors present the same advantages for the driving of woodworking machinery as in the driving of metal-working machine tools. A great advantage in both cases is that additions can be made to the original shop, and rearrangements of the machinery are possible without interfering with the machines already installed. In the pattern shop, particularly, where the machines are generally operated intermittently and run at high speed, the individual motor drive is economical. The application of motors to woodworking machines and the horsepower required for different sizes of band saws, resawing machines, circular saws, swing saws, jointers or hand planers, surfacers, wood-turning lathes, mortising machines, wood shapers, tenoning machines, and sanding machines are given in the paragraphs on *Electric Drive for Woodworking Machinery*, Vol. IV, p. 439.

Wiring for Motor-driven Machinery. — Frequently, a man who is not an electrician will be required to make the connections for a motor that is installed for driving machine tools. This work is comparatively simple, and with proper directions any mechanic should be able to do this work, although, when possible, it is advisable to employ an electrician. Many electricians, however, used to house-wiring and lighting work, may not know how to properly arrange the wiring for motor-driven machine tools, and directions for doing this work will prove of value to them also. The section WIRING FOR MOTOR-DRIVEN MACHINERY, Vol. VI, p. 532, gives explicit directions for this kind of work, and also complete details as to the accessories and materials required in doing the work.

Motor Applications for General Purposes. — Electric motors are applied, at the present time, for supplying power to practically all classes of machinery. The rapidity with which electric motor drive has been adopted in all the branches of industry is due to the convenience of the motor drive. The electric motor, as designed today, requires little attention, and electric energy can be conveniently transmitted to it, no matter where it is located. Hence the motor can be placed at the very point where the power is required, long transmissions by means of shafts, belting, chain or rope drives being omitted. The ENCYCLOPEDIA deals with the applications of motors to the more important machines and appliances used in the industries. The driving of machine tools has already been referred to. Motor applications for a number of other purposes are dealt with in the section on MOTOR APPLICATIONS, Vol. IV, p. 433. The application to air compressors is treated on page 434; crane motors, specifying the power required and the types of motors suitable for the work, on pages 434–436, inclusive; and the use of electric motors for mine hoists, which is one of the important applications of motors in the mining industry, on page 436. The conditions under which a mine-hoist motor works make it necessary to have an absolutely reliable source of power and one that will work with the least amount of attention, and which, if possible, can be supplied with energy from a central power generating station. The electric motor fills all these requirements. Electric motors are also applied to mine locomotives used in the mines for hauling coal or ore (Vol. IV, p. 438). Other applications in the mining industry are for rock drills, electric coal cutters, and electric shovels (Vol. IV, p. 439).

An important application of motor drive, which has only been recently developed to its full extent, is that for rolling mills. In rolling mill drives, alternating-current motors are generally required. At the present time, motors are used both for main roll drive in steel mills and for the drive of auxiliaries. The main roll drive has been developed at a more recent date, while the drive for auxiliaries, cranes, charging machines, screw-downs, etc., has been used for the last twenty-five years. These auxiliaries require frequent starting, stopping, and reversing, and the service is of a particularly severe nature; hence, a motor has been developed for this particular service, known as the *mill-type* motor. The applications of electric motors both to main roll drive and auxiliaries are dealt with in the article ROLLING MILLS, ELECTRIC DRIVE, Vol. V, p. 284.

Application of Motors to Fans and Blowers. — A very general application of electric motors is met with in the operation of fans and blowers. Motors have been developed for this service from the extremely small type used for the ordinary desk fan to the large motors required for the blowers employed in foundries and metallurgical work. Fan motors require characteristics somewhat different from those required in machine tool drive, the requirements being more similar to those required for centrifugal pump drive, in which the load increases as the speed rises. The types of motors used for constant and adjustable speed service, and the control methods, as well as the horsepower required, are subjects dealt with in the paragraphs on *Motor Drive for Fans and Blowers*, Vol. III, p. 108.

Electric Drive for Pumps. — The economy with which electric energy can be generated and transmitted and the high operating efficiency of the electric motor, its adaptability for intermittent pumping operation, the flexibility of location, and the small floor space required are some of the important advantages of electric motor drive for pumps and pumping installations. Centrifugal pumps are especially adapted to be direct-connected to an electric motor, and this is a common method of driving this class of pumps. Motors are also used for driving reciprocating pumps, but these being of a slow-speed type require slow-speed motors, if direct-connected. Frequently, however, the motors are connected to the pumps by belts, gearing, or chain drives. A review of the different kinds of motors required for different kinds of pumps, and the horsepower of motors for pumping a given amount of water against a known head, are treated in the paragraphs headed *Methods of Driving Pumps*, Vol. V, p. 208, in the general article on PUMPS.

Electric Brakes. — In addition to the use of electric motors for cranes and hoists, the electric current is applied to hoisting devices for braking purposes, electric brakes being important auxiliaries in the proper operation of hoisting appliances. There are a number of different kinds of electric brakes which are dealt with in the article BRAKES, ELECTRIC, Vol. I, p. 488.

Electric Lighting. — One of the earliest, and, for many years, one of the most extensive applications of electric current was for electric lighting. In the early days, arc lamps were used almost exclusively when high candlepowers were required, but of recent years incandescent as well as special types of lamps have been developed, and arc-lamp lighting is, at present, used to a comparatively small extent, except in existing installations. The rapid development of electric lighting is one of the most remarkable signs of the progress in the application of electricity. The convenience with which wires may be strung for conveying electric energy, as compared with the arrangement of piping for conveying gas for lighting purposes, is apparent to anyone. The ENCYCLOPEDIA does not deal in great detail with this phase of electrical engineering, as it may be considered as being somewhat outside of the field of this work. Nevertheless, it contains sufficient material on this subject to give the student of electricity and its applications a comprehensive treatise on the different kinds of electric lamps used, their efficiency and application, together with a brief review of the problems presented in the distribution of electric current for lighting purposes. These subjects are dealt with in the article on ELECTRIC LIGHTING, Vol. II, p. 544. In addition, the ENCYCLOPEDIA contains articles on special types of electric lamps which have been developed from time to time to meet the needs for better or more economical means of using the electric current for lighting purposes. Among these lamps are the NERNST LAMP, Vol. IV, p. 487; the MOORE

TUBE LIGHT, Vol. IV, p. 430; and the MERCURY VAPOR LAMP, Vol. IV, p. 347.

Application of Electricity in Electrometallurgy. — The application of electricity to electrometallurgy has only just begun. It is safe to say that, in the future, electric energy will be used to an ever increasing extent in extracting metals from their ores. The electric energy is used in metallurgy in the application of either electrolytic methods — that is, where metals are deposited by means of chemical compounds; or in electrothermal methods — in which the metals are obtained by means of the heat produced in electric furnaces. A brief review of the subject of electrometallurgy and its subdivision into electrolytic and electrothermal methods is given in the article on ELECTROMETALLURGY, Vol. III, p. 41, which should be read first in order to obtain a perspective of the use of electricity for electrometallurgical purposes. The details of electrolytic processes are dealt with more completely in the section on ELECTROLYTIC REFINING OF METALS, Vol. III, p. 33, in which the refining of copper, silver, gold, and lead is dealt with. The electrolytic refining of copper has become one of the important processes in the production of copper. Enormous quantities of copper are now produced in this manner. Four-fifths of the copper produced in the United States is refined by electrolytic methods, and when it is considered that the United States furnishes more than one-half of the world's supply of copper, the significance of these figures becomes apparent. Great quantities of electric current, therefore, are used in this industry alone.

In the electrothermal methods for obtaining the metals from their ores, electric furnaces are used. The electric furnaces employed for metallurgical purposes are mainly of the arc or induction type. Resistance furnaces are also used to a limited extent for metals which melt at a reasonably low temperature, but, otherwise, resistance furnaces are mainly employed for heating purposes only, as in the hardening and tempering of steel. Electric furnaces both for the refining of metals and for the heating and melting of metals are dealt with in the section FURNACES, ELECTRIC, Vol. III, p. 240. A study of the characteristics of the electric current in the section ELECTRICITY AND MAGNETISM, Vol. II, pp. 527–535, inclusive, is required in order to fully understand the section dealing with electric furnaces.

Electroplating. — Another important field in which the electrolytic action of electricity is used is in *electroplating* — that is, the deposition of one metal on the surface of another by passing an electric current through a solution in which the metal to be coated is immersed. Electroplating is one of the valuable arts that has been developed to a remarkable degree during the last half century. By means of this process, it is possible to obtain all the advantages of the so-called noble metals — gold, silver, and platinum — for nearly all purposes for which these would be used, without the necessity of making the whole object from these expensive metals. Properly plated articles of cheaper metals or alloys have the same appearance and the same resistance to corrosion in the air or in the presence of certain acids, as objects made entirely from the more expensive metal, and, when the deposited coating is sufficiently heavy, the durability of objects so treated meets all reasonable requirements. Hence, the electroplating process has furnished to the world one of the most valuable processes in the economical use of the more costly metals. Plating, however, is by no means confined to gold, silver, and platinum. Practically any metal can be deposited on another metal by means of electroplating, for the purpose of improving the appearance of the metal covered, or its wearing qualities, or both. Nickel, which has remarkable qualities for resisting corrosion in the atmosphere, is frequently deposited upon other metals.

The article ELECTROPLATING, Vol. III, p. 41, covers, specifically, nickel-plating, cobalt-plating, iron-plating, tin-plating, copper-plating, brass-plating, zinc-plating, silver-plating, gold-plating, platinum-plating, and palladium-plating, giving in each case the baths that are required and general directions for the work. This section will be found useful both for study and for reference purposes. The electroplating of aluminum has been considered difficult, if not impossible. A method claimed to be successful, if properly carried out, is explained in the brief article ELECTROPLATING ALUMINUM, Vol. III, p. 47. This subject is also referred to in the paragraph *Aluminum Pickling Bath*, Vol. III, p. 43. The electroplating of zinc-alloy die-castings, which has become an important part of the electroplating industry since the die-casting process has been so highly developed, is covered in the article ELECTROPLATING ZINC-ALLOY DIE-CASTINGS, Vol. III, p. 48. This article deals with the copper-plating, brass-plating, nickel-plating, silver-plating, and gold-plating of die-castings. ELECTROTYPING, Vol. III, p. 49, is a special application of the electroplating process in the printing industries. The method of electrotyping is one of the earliest applications of the electric current, it having been discovered about 1837.

Electrolysis and its Mitigation. — While the electric current is one of the most valuable aids in modern life, its effects are not always beneficial. The action of the electric current in some instances becomes difficult to control, and its effects are destructive. The corrosion of metal work in the earth or in structures, due to stray currents of electric energy, is known as *electrolysis*. Since the development of electric railroads, electrolysis has always caused more or less trouble, and is a subject to which a great deal of attention has been given during recent years. A comprehensive review of the subject of electrolytic corrosion and means that have been adopted for its mitigation, as well as a study of the effectiveness of these means, will be found in the article on ELECTROLYSIS, Vol. III, p. 28. This subject is one of great importance to the electrical engineer engaged in power plant and substation work, electric railway work, or in civil engineering work having to do with the distribution of water and gas piping through streets or in areas in the vicinity of electric railways.

Electric Shock and Care of Electric Burns. — The danger of electric currents to the human body, if a current of sufficiently high voltage and amperage should pass through the body as a conductor, is quite generally realized, but comparatively few know what to do in such an emergency. The result of such an accidental contact with an electric current is generally known as an *electric shock*. Everyone who works around electric machinery, electric conductors, or machines driven by electric power should have an elementary knowledge of what to do in case of an accident, so that a victim subjected to an electric shock could be revived, which can usually be done by the prompt and continued use of artificial respiration. The ENCYCLOPEDIA, therefore, contains an article on ELECTRIC SHOCK, Vol. III, p. 26, which gives specific and detailed rules on how to proceed in case of an accident. This article cannot be used for reference, because there is no time to refer to the printed page when an accident has occurred. It is quite important that everyone should read and study the directions there given, so that he would know immediately, in case of an accident, how to proceed. The article also gives directions for the first care of electric burns, which, if possible, should be attended to immediately, even though a doctor is called in to take care of the burns. Electricians usually recognize the great danger attendant upon the use of electric current, but operators of machine tools driven by electric motors do not always fully appreciate the dangers from exposed wires or from machines that have become charged, and too much stress cannot be laid upon this point. In repairing or adjusting electrical apparatus, safety should not be taken for granted, but before working on the mechanism, the switch which shuts off the electric current should always be thrown, and preferably locked, so that the circuit cannot be accidentally closed.

PUMPING, HYDRAULIC, AND PNEUMATIC MACHINERY

THE use of mechanical means for elevating water to a higher level dates back to ancient times. A primitive form of pump used for raising water from deep wells for land irrigation consisted of an oxhide bucket or bag of funnel shape, open at both the large and small ends. This bag, after being filled with water, was raised by oxen, the connecting ropes attached to each end being so arranged that the spout or small end of the bag stopped at the brink of the well while the remaining part was raised high enough to discharge the water. Among other primitive forms of pumping machinery may be mentioned the bucket wheels described by Vitruvius, a Roman engineer and architect about the beginning of the first century. These wheels or circular frames were equipped with buckets and, when revolved by the motion of a stream, water was carried upward by the succession of buckets and discharged into a trough. An endless chain of buckets passing over a revolving sprocket wheel is another ancient type of pumping device, and many hand-operated pumps of the present day operate on this principle. The invention of the steam engine and the development of the manufacture of iron and steel pipes have resulted not only in the production of pumping machinery capable of rapidly elevating and conveying vast quantities of water or other liquids, but also in the use of water or other liquids under pressure for operating many forms of mechanisms.

The use of air or "pneumatic" devices as a means of transmitting energy has been known for centuries, but its application to practical work is quite recent; in fact, its use began about 1861 in connection with the construction of the Mount Cenis tunnel through the Alps between France and Italy, which is nearly eight miles long. Rock drills operated by compressed air were introduced after working four years entirely with hand labor; the result was that an average progress of nine inches per day on each side of the tunnel was increased to approximately four feet per day. At a later period, compressed air was applied to mining work. In 1869, George Westinghouse invented the "straight air brake," for use on railway trains, which later was superseded by the "automatic air brake" which is now one of the most important applications of compressed air. The transmission of power by compressed air is also applied, at the present time, in a great many manufacturing industries, although this method has been replaced by the use of electricity for certain classes of work.

Pumping Machinery. — The study of pumping machinery may be divided into two general divisions — one including the pumps proper, and the other the means of driving them. In considering the pump, or that part of the machine designed either to elevate or convey liquids, or to exhaust air or gases from closed vessels, it is important to understand the physical laws which govern the action of liquids and gases when subjected to pressure, changes of temperature, etc., as well as the details of pump construction. This point may be illustrated by a simple incident in the experience of a "trouble man" employed by a builder of pumping machinery. The suction valves of a high-pressure pump had given considerable trouble, evidently due to a leak through the valves on the discharge stroke, as indicated by a hissing sound when the pump was in motion. The excessive leak, however, had not occurred until a new set of valves made by a local mechanic had been installed. These valves were of the poppet type and on top of each there was a guiding stem that was a sliding fit in a hole drilled in a cap above. On the original valves made by the manufacturer, the stems were fluted so that air would be admitted to the space above them. On the new valves these flutes were omitted, with the result that they closed so slowly, owing to the partial vacuum formed above the valve-stems during their descent, that there was considerable discharge through the valves during part of the discharge stroke. This incident is referred to merely to show that a little elementary knowledge of physics, or of some other subject which may be indirectly related to a certain branch of mechanical work, is often of greater help to the machinist or engineer than practical mechanical training. The section on PUMPS, Vol. V, p. 183, explains the principles governing pump operation and includes detailed descriptions of the more important types, together with formulas and general information relating to pump design.

Hydraulic Jacks and Presses. — The most powerful of the jacks used for lifting heavy loads are hydraulically operated, whereas many of the smaller jacks of the type used for comparatively light work are equipped with a screw. The principal types, as well as other less important designs, are described in the article on JACKS, Vol. IV, p. 87, which includes general information on hydraulic jack defects, the care of hydraulic jacks, and the methods of repairing them.

Presses of the type used primarily for supplying great pressure are also hydraulically operated. These hydraulic or hydrostatic presses are applied in many different ways either in connection with forging operations, drawing sheet metals, the assembling of tightly fitting machine parts, or wherever a slow powerful movement is essential. Hydraulic press construction and design is dealt with in Vol. IV, p. 34. (See also ACCUMULATORS, HYDRAULIC, Vol. I, p. 13.)

Air Compressors. — Air, when compressed by a machine designed for that purpose and stored in a tank, represents accumulated energy, and when the air is conveyed through pipes to mechanical devices adapted to pneumatic operation, it provides a convenient method of transmitting power. The compressing machine, or "air compressor," is arranged to receive the air at the ordinary atmospheric pressure and serves to increase this pressure according to requirements. Compressors differ in the arrangement and method of operating the valves that control the admission and discharge of air to and from the air cylinder, and also in the manner of driving the compressing member. Typical designs are described in the section on AIR COMPRESSORS, Vol. I, p. 31, which also deals with the applications of compressed air and air compressor computations. In conjunction with this subject, the article on AIR COMPRESSION, Vol. I, p. 30, should also be studied to obtain a clear understanding of the laws and principles governing air compression. The following articles also have a direct bearing on this general subject: AIR, Vol. I, p. 27; GASES, Vol. III, p. 307; ATMOSPHERIC PRESSURE, Vol. I, p. 150; AIR RECEIVERS, Vol. I, p. 58; AIR STORAGE TANKS, Vol. I, p. 59; INTERCOOLERS FOR AIR COMPRESSORS, Vol. IV, p. 68; and AIR COMPRESSOR TESTING, Vol. I, p. 47.

Pneumatic Tools. — One of the most valuable pneumatic tools in use at the present time is the pneumatic hammer. This tool is indispensable in structural work for riveting, and in boiler work for riveting, chipping, calking, etc., and it is also very useful in many machine shops and other manufacturing plants. (See PNEUMATIC HAMMERS, Vol. V, p. 121.) Some of the larger power hammers used for forging operations are also driven by compressed air. (See Vol. III, p. 500.) Another important application of compressed air in machine shops is in its use for driving portable drilling machines of the type described in Vol. V, p. 120, and also for operating hoists of the kind referred to in Vol. IV, p. 28.

Fans and Blowers. — Fans are used in shops and factories either for producing a strong outward current of air for exhausting fine particles of dust from grinding and polishing wheels, woodworking machines, etc., or for supplying a low pressure of air for artificial drafts for boilers, etc. Different types of fans and the principles of fan design are dealt with in the section on FANS, Vol. III, p. 102. BLOWERS, Vol. I, p. 383, are designed to supply low air pressures and range in size from the small fan-shaped type to the large blowing engines used in blast furnaces.

MACHINE SHOP ORGANIZATION AND MANAGEMENT

WHILE the ENCYCLOPEDIA is intended to deal principally with the mechanical problems met with in drafting-rooms and machine shops, and to impart such information as is necessary for the solution of these problems, some branches of machine shop organization and management are so closely related to manufacturing that they should not be excluded from a work of this kind. No attempt has been made to cover the business side, the cost keeping, or the sales department of industrial organizations, but articles have been included on the problems of management which relate to the mechanical departments of a shop or factory. Many of these problems are so closely interwoven with engineering work that only an engineer is fully qualified to deal with them, and for that reason they have a proper place in a mechanical engineering encyclopedia. In order to present a general review of the subject of management, a broad outline of the functions of industrial management and the different types of management in vogue has also been included.

Principles of Industrial Management. — The principles of industrial management, as far as these pertain particularly to the work of the engineer, are dealt with in the section on MANAGEMENT, Vol. IV, p. 310. This article outlines the three more or less distinct classes of management in general use — the so-called "conventional" or "unsystematized" management; "systematized" management; and "scientific" management, the latter being a development of recent years. The conditions obtaining under these types of management and the methods used in each are briefly described, in order to give the student of this subject a broad and comprehensive view of the functions of industrial management, the duties of the administrative department, and the methods by means of which these duties are discharged. Particular stress has been laid in this article upon scientific management, as this system, when properly applied, is doubtless superior to any other. Serious objections have been raised to scientific management, but most of these are due to a misunderstanding of the principles involved. The more important of these objections are also dealt with. (Vol. IV, p. 315.)

Special articles on some of the phases of scientific management appear under specific headings in different volumes of the ENCYCLOPEDIA. One of the fundamental methods on which scientific management is based is that of *time study*, the principles of which are outlined in a brief article on this subject in Vol. VI, p. 287. The wage systems used under scientific management are of the highest importance, and many of the failures of the system have been due to a lack of recognition of this important factor. The *bonus system*, which is the system of paying wages under scientific management, is outlined in an article on this subject, in Vol. I, p. 456, and different kinds of wage systems in general use are dealt with in the article WAGE SYSTEMS, Vol. VI, p. 441.

General Principles of Cost Estimating. — One of the important details of industrial management is that of preparing a satisfactory system for the estimating of costs of machines and devices to be built. The work of cost estimating is closely allied with the engineering work, because it is impossible for any one not thoroughly familiar with the mechanical processes to accurately estimate the cost of building a machine the design of which is still on paper. The methods of cost estimating differ greatly, but here, as in other phases of administrative work, there are a few fundamental principles that may be laid down and which, if followed, will make it possible to devise a system of cost estimating which will prove successful. These principles are dealt with in the article on COST ESTIMATING, Vol. II, p. 220.

Appraisal of Manufacturing Plants. — Another duty of the management — often neglected — is that of making an accurate appraisal of the value of the plant from time to time. Without such an appraisal being made, the financial side of the operation of the shop is often based on erroneous assumptions and the assets of the plant are likely to be overestimated. Appraisals are also necessary for fire insurance and in cases where used machines or plants are bought or sold. The methods used in the appraisal of machine tools and manufacturing plants generally are dealt with in APPRAISAL OF MANUFACTURING PLANTS, Vol. I, p. 104, and some tabulated data relating to the depreciation of machinery and buildings which is useful when making appraisals will also be found in the article on DEPRECIATION, Vol. II, p. 305.

Systems for Productive Departments. — It is not within the scope of an encyclopedic work to describe in detail different kinds of shop systems. Were it possible to adapt *one* system to all, or at least a great number of industrial undertakings, it would be worth while to describe a system in detail, but no shop system is applicable in its entirety to any other shop, except one manufacturing exactly the same kind of machinery, under the same conditions, and in the same quantities, which is a most unusual case. Hence, the ENCYCLOPEDIA does not include details of shop systems, but explains the broad underlying principles with which every executive and engineer in the mechanical industries should be familiar. The article on PRODUCTION SYSTEMS, Vol. V, p. 165, outlines the principles of organization, the methods of handling orders and preparing lists for materials required in the shop, the routing of the work through the shop, the ordering of material for the shop, the following-up of ordered material, and the records kept of articles manufactured for stock. No system is outlined which would be directly applicable to any one shop, but principles are laid down which either directly or with modifications are applicable to all shops. The student of management will obtain a better perspective of the principles involved when the subject is dealt with in this manner.

The stock-keeping is so important a part of the successful management of an industrial undertaking that a special article on this subject has been prepared, outlining the principles that must be taken into consideration in organizing a stock-keeping department for a medium size or large plant. (See STOCK-KEEPING, Vol. VI, p. 74.)

Specific Systems and Methods. — There are some departments in a machine shop in which the work done is of a nature which can be more thoroughly standardized than the work in other departments, and for which rules and systems may be laid down which are of more general application than would be the systems for other departments. One of these departments is the drafting-room. It is possible to lay down in greater detail the principal requirements of a drafting-room system than it would be to outline a shop system in the same manner. This subject is, therefore, dealt with in a section by itself under DRAFTING-ROOM SYSTEMS, Vol. II, p. 398.

Another of the departments in the shop for which a definite system may be laid down, which would be applicable to the great majority of shops, is the tool-supply room from which the operators obtain special tools used in the manufacturing operations. Check systems are used for these tool-rooms, based generally on the principle that the operator hands the tool-room stock-keeper a check in return for the tool given to him. There are a number of these check systems, some suitable for small shops while others are better adapted to larger plants. These are described in the article CHECK SYSTEMS FOR TOOL-ROOMS, Vol. II, p. 91.

Packing of Machinery for Export. — A department that is often neglected as far as the personal attention of the management is concerned is the shipping department. It is assumed that the mere packing of machinery and machine details into boxes or crates requires no special skill or attention. This may be true in the case of smaller machines and tools, especially when packed for the domestic trade only. When packing machinery for the foreign trade, however, the packing requires considerable attention, and, unless properly handled, many difficulties will be met with that could easily have been avoided. The requirements in the packing of machinery for export are much more severe than those for the domestic trade. There are various requirements in the marking of the boxes or crates that must not be neglected if serious delays at the foreign port of entry are to be avoided. The article PACKING MACHINERY FOR EXPORT, Vol. IV, p. 518, outlines in considerable detail the methods that should be adopted in order to avoid the difficulties that are otherwise certain to be encountered. This article describes the preparation of machines, the protection of finished surfaces, the packing cases, and the methods of marking. Different countries require somewhat different markings on shipments of this character, so that, in addition to the information given in the article referred to, it is well to obtain from the Department of Commerce definite information as to the specific marking required.

Patents and Patentable Inventions. — The subject of patents is one with which the engineering side of the management of an industrial undertaking must frequently deal. There are a number of questions that may seriously influence the conditions under which an industrial plant will operate. Not only are there a number of problems in connection with the obtaining of patents for machines or devices that are developed within the plant, but it is also important to avoid infringement of other existing patents, and to understand properly the rights of inventors and patent rights between employer and employee. These subjects are dealt with in considerable detail in the article on PATENTS, Vol. IV, p. 523.

Industrial Publication Department. — Another part of the work in connection with the proper management of an industrial plant relates to the publicity given to the machines and devices built. In the ENCYCLOPEDIA, that part of the publicity which relates to advertising and which may be considered as a business problem, pure and simple, has not been dealt with, but there is another important phase of the publicity department, relating to the technical description of machinery and devices which are published either in catalogues or in the reading pages of engineering and trade journals. These descriptions, in order to be intelligible and of value to other engineers and mechanics, must be prepared by the mechanical department. The engineer naturally has little or no experience along these lines, but a few guiding principles may be obtained from ARTICLES FOR PUBLICATION, Vol. I, p. 126. In the preparation of catalogues, standard sizes are now generally adopted, these standard sizes being specified in the section CATALOGUES, Vol. II, p. 35. In preparing matter for publication, whether in engineering journals, trade papers, or catalogues, half-tone illustrations made from photographs are an important item. Industrial photography, or the making of photographs in shops and factories, often requires special methods. This work can often be done satisfactorily by an amateur, after he has obtained a certain amount of experience, especially if approved methods are followed from the beginning. In a great number of shops throughout the country, the photographing of machines and devices for publication purposes is done by some man in the organization detailed to do this work — quite frequently a draftsman. In the larger plants, an industrial photographer who devotes all his time to this kind of work is employed. The subject of photography in connection with the proper presentation of machinery in published material is so important that a very comprehensive treatise on this subject has been included in the ENCYCLOPEDIA under the heading PHOTOGRAPHY, INDUSTRIAL, Vol. V, p. 12.

Prevention of Industrial Accidents. — The prevention of accidents in shops and factories received but little attention until a few years ago. At that time, however, there was a general awakening to the enormous economic loss due to the thousands of industrial accidents that occur daily throughout the country. The causes of accidents were investigated and organized efforts have been made by many large corporations to eliminate preventable accidents as far as possible. The policies that are to be adhered to with regard to the prevention of accidents are determined by the management, but it falls upon the engineer to carry out the measures in a proper way. The causes of accidents and the general means for their prevention are comprehensively dealt with in the article on ACCIDENT PREVENTION, Vol. I, p. 7, and the mechanical features in connection with the design of guards for dangerous machine parts, in the article on SAFEGUARDS FOR MACHINE TOOLS, Vol. V, p. 301. Dangers to workmen's eyes, especially when working at grinding machines, are dealt with in EYE PROTECTION IN THE INDUSTRIES, Vol. III, p. 90. Dangers in connection with electrical machinery and the methods for restoring a victim of such an accident by artificial respiration is treated in the section ELECTRIC SHOCK, Vol. III, p. 26. Finally, the general emergency methods adopted for fire protection in factories are outlined in FIRE PROTECTION IN FACTORIES, Vol. III, p. 143, and in SPONTANEOUS COMBUSTION, Vol. V, p. 479.

Mechanical Education of Apprentices. — Recent years have proved conclusively the absolute need for organized efforts in the education of apprentices, so that the supply of skilled workmen may be kept normal and great enough to meet the demands of the industries. Therefore, one of the important problems in connection with the management of every industrial organization is to provide means whereby a sufficient number of young men may be properly trained in the mechanical trades. The old-time apprentice system has not proved adaptable to modern conditions without some modifications. Special apprentice schools have, therefore, been established by the larger organizations, and coöperative methods have been adopted by manufacturers whose plants are too small to warrant the establishment of an independent apprentice school. Trade schools also have been established for the teaching of mechanical trades. Every student of industrial management must be familiar with what has been done along these lines, and will find a comprehensive review of the subject in the article APPRENTICESHIP SYSTEMS, Vol. I, p. 107, and TRADE SCHOOLS, Vol. VI, p. 302. These articles contain suggestions that may be adopted in case similar institutions are planned.

Location and Design of Factory Buildings. — A phase of industrial management that requires the advice and judgment of the engineer more than that of the general business or sales department is the planning of new factories or additions to existing plants. Space, therefore, has been given in the ENCYCLOPEDIA to articles of a general nature that would assist the mechanical engineer in planning factory buildings. Much of the work in connection with such planning, especially in the case of additions to existing plants, falls upon the mechanical organization of the plant. A draftsman or engineer is often detailed to make the preliminary survey for the intended addition, or, in the case of a new plant, an engineer is required to present a report to the management which necessitates a preliminary survey. An article on SURVEYING FOR SHOP CONSTRUCTION, Vol. VI, p. 129, outlines the elementary principles required in work of this kind. The article on FACTORY BUILDINGS, Vol. III, p. 94, deals with the location and design of these buildings; describes the different types of factory buildings, outlining the advantages of each; presents a condensed outline of the data required for planning shops; and contains an example of a well-designed shop, indicating the method that the engineer would follow in planning an industrial plant. Special articles relating to details in shop construction that should be studied in this connection are DRAFTING-ROOM LIGHTING, Vol. II, p. 396; FLOORS FOR MACHINE SHOPS, Vol. III, p. 157; and FOUNDATIONS FOR MACHINERY, Vol. III, p. 205. In connection with the article on foundations for machinery, data for concrete foundations will be obtained from the article CONCRETE, Vol. II, p. 172.

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